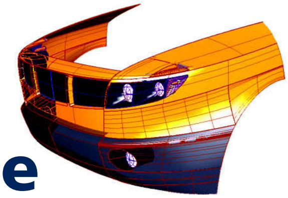
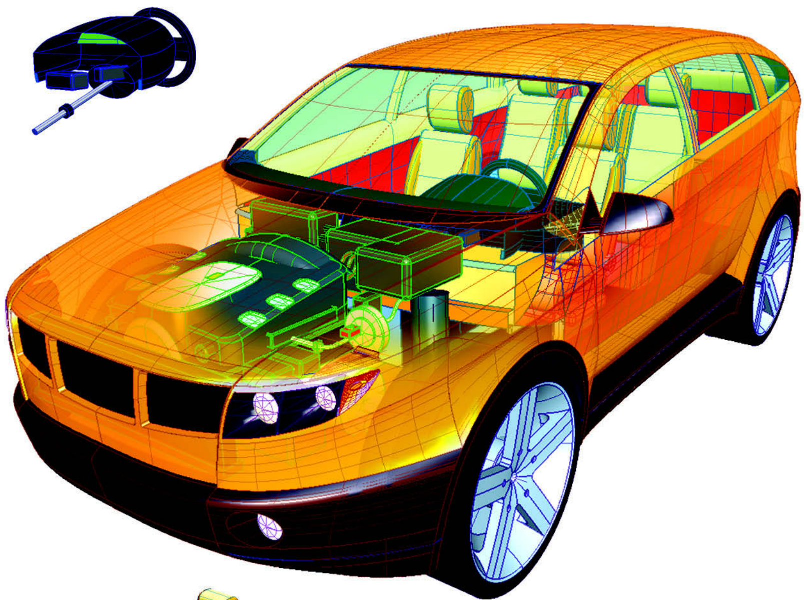
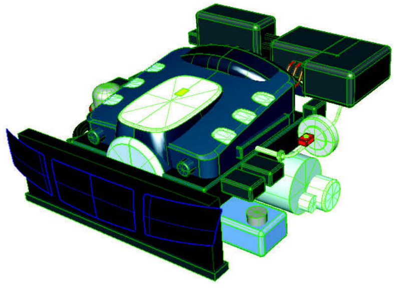
PETER MILTENBURG

Effects of Modular Sourcing on Manufacturing Flexibility in the Automotive Industry







Effects of modular sourcing on manufacturing flexibility in the automotive industry

A study among German OEMs

Peter Miltenburg

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A study among German OEMs

Effecten van modulair toeleveren op de productie flexibiliteit in de automobiel industrie

Een studie onder Duitse OEMs

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Preface

I would like to express my gratitude to many individuals who shared their time and expertise with me. During my study of Economics at the Erasmus University Rotterdam and the Haas Business School in Berkeley, I learned a lot about the dynamics of the industrial environment and the organisation of manufacturing systems. At the Fraunhofer Institute (IPA) in Stuttgart I gained firsthand practical insights into the modularity concept in the automotive industry. After receiving my Masters degree, I gained further insight from my consulting work in the automotive industry for Arthur D. Little. During this time, I had contact with many OEMs and suppliers and concluded that organisations have difficulties in understanding the concept of manufacturing flexibility and how this is affected by modular sourcing. Since practitioners could only describe the effects in very general terms, my interest was raised and the effort to write this dissertation was undertaken.

I want to start thanking my supervisors; those people who gave me intellectual energy to end this study successfully. First of all, I want to thank Piet Moerman, who guided the initial steps of this dissertation. His views on industrial economics were always refreshing. Furthermore, my supervisors Jaap Paauwe and Harry Commandeur proved to be excellent sparring partners in the entire process. Ernst Verwaal deserves a lot of gratitude for the help he gave me in wrapping up the statistical analysis. My appreciation furthermore goes out to Remko van Hoek and Allan Harrison (Cranfield University, UK) who made some very valuable contributions during the final stages.

Secondly, I would like to thank the numerous people who I interviewed and have provided me with insights from modular sourcing applications in practice. I especially would like to thank the following persons who have supported me in conducting case studies. From BMW AG, they are: Peter Hörndlein, Sybille Drolshagen, and Karsten Peddinghausen. From Volkswagen AG they are: Dr. Jan Hickmann, Detlef Kaufhold, and Martin Gusse. From Audi AG they are: Jan Scholer, Oliver Hajek, and Emil Kauschitz. From Lamborghini S.p.A they are Federico Foschini and Luigi Monni. From DaimlerChrysler AG they are: Philipp Hartmann, Sebastian Beier, and Georges Massing. Furthermore, Jan Weydringer (Bugatti Automobiles S.A.S), Thomas Weimar (Dr. Ing. h.c. F. Porsche AG), and Marcos Felin (General Motors). Although the primary purpose of this dissertation is academic, I sincerely hope this study confirms their expectations in terms of practicability.

Finally, I want to thank some people who cannot be classified in the groups mentioned above. Jeroen de Vries, Erwin Bal and Wildrik v/d Plassche always provided mental support after supervisory sessions. Amongst my former colleagues from Arthur D. Little there were many that contributed in one form or another to the culmination of this study. I am grateful to Dr. Tom Sommerlatte, Dr. Norbert Klapper, Dr. Michael Kleer, Dr. Matthias Grundmann, Ralf Landmann, Jochen Funk, Jürgen Ungerhofer, Michael Mandat, Kilian Fruehauf, Thomas Brugger, Armin Skocic, and Björn Hauber. I am also grateful to ERIM in the person of Wilfred Mijnhardt for having taken care of the publication of this study.

Last, but certainly not least, I want to thank Chrissi for her understanding and support during the entire process. Without her, this study would not have been possible.

Peter Miltenburg
November 2003
Munich, Germany

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1 Introduction & problem definition

Acceleration of change takes place in our minds as well as in our environment… The most important change… is in the way we try to understand the world, and in our conception of its nature. However the large and growing literature on change and its management focuses on its objective rather than subjective aspects. It assumes that most of the managerial problems created by change derive from its rate. This may be true, but it is apparent that we cannot deal with change effectively unless we understand its nature.

(Ackoff, 1981, p.5)

1.1 Introduction

Modular sourcing represents a departure from 'traditional' sourcing methods since the objective is to decrease both product and process complexity (van Hoek, 1998). Modular sourcing enables original equipment manufacturers (OEMs) to better cope with this complexity and, when applied appropriately, can increase manufacturing flexibility.

In a modular sourcing relationship an internal or external supplier develops and produces a vehicle module (complex part) on behalf of the OEM. Such a module supplier has an excellent process and product know-how and even develops key technology at its own risk. The transfer of complexity to module suppliers allows OEMs to better focus on their core activities and improves the manufacturing flexibility. In order to develop and produce innovative solutions, module suppliers need to heavily invest in state-of-the-art machines and technology. These efforts are compensated by high profit margins and long-term supply contracts with OEMs. Moreover, modular sourcing relationships are characterised by a high level of mutual dependence. The used coordination structures and control functions have to ensure that the engagement remains valuable for all parties involved. In other words, a modular sourcing relationship functions as a symbiosis: both OEM and supplier benefit from the relationship and are, at the same time, highly interdependent.

Studies in the field of logistics and sourcing strategies (e.g. Eicke & Femerling, 1991; Wolters, 1995; Piller & Waringer, 1999) have contributed substantially to a better understanding of the modular sourcing concept. Since the initial publication of Starr (1965) on the modularity concept, many others have studied aspects such as: product classifications (e.g. Abernathy & Utterback, 1978), technology applied (e.g. Dudenhöffer, 1997) and platform strategies (e.g.

Wilhelm, 1997). Not only did prior empirical research contribute to theoretical knowledge development, but it also collected empirical findings concerning the implications for buyer-supplier relationships and their development directions (Wildemann, 1996; Dudenhöffer, 1997; Wildemann, 1998a; Piller & Waringer, 1999). Manufacturing flexibility has been studied quite extensively as well and its potential in achieving a competitive advantage has been widely recognised by researchers (e.g. Upton, 1995; Gupta & Somers, 1992, 1996; Volberda, 1999; Koste, 1999). Moreover, these studies provided insight in dimensions and scales that can be used to describe and measure manufacturing flexibility.

However, most empirical research has been aimed at one actor exclusively and has neglected the interdependencies between modular sourcing and manufacturing flexibility. Moreover, the attention of previous research on a macro (industrial environment) and meso (automotive industry) level tends to underestimate the organisation of manufacturing activities on a micro (plant) level. In addition, the existing flexibility literature is primarily focussed on internal processes and does not explicitly observe the interfaces with other supply chain parties.

Furthermore, the theoretical basis of the developed models is limited, which makes prior domain specifications[1] of manufacturing flexibility questionable (Churchill, 1979; Venkatraman & Grant, 1986). Finally, the majority of manufacturing flexibility publications have an Anglo-Saxon origin. Since the design of organisations and their related systems are culturally influenced (Cadogan *et al*., 1999), it becomes questionable as to whether the existing conceptual models can be applied to German organisations.

Based on a solid theoretical analysis of the two research constructs, a conceptual framework will be developed in this study. This conceptual framework grasps the effects of modular sourcing on manufacturing flexibility and observes several variables that influence this relationship. In order to develop and validate this conceptual framework both exploratory and survey-based research has been used.

1.2 Problem definition & objectives

The basic principles of a modular product design stem from the 1960's and were first applied in the computer hardware industry. In the 1980's the automotive industry followed and was able to combine modular vehicle architectures with

[1] In terms of Churchill (1979), the domain is the description of the research construct.

technology platforms. In this study modules are predominantly understood as assembly modules on an operational level.

The combination of modular product architectures and the use of technology platforms were the basis for the successive decoupling of development and production of modules. This had a tremendous impact on organisations in this industry and resulted in a trend towards more outsourcing and a focus on a limited number of core activities. In the effort to optimise modular sourcing applications and improve the flexibility of core activities, OEMs have been experimenting with new supply chain configurations. These developments need to be studied in more detail to assess the impact of modular sourcing on the flexibility of manufacturing systems and beyond that, the structure of the automotive industry.

The choice to study the effects of modular sourcing in the automotive industry is relatively straightforward. First of all, the automotive industry is the worlds' largest 'manufacturing activity' (Womack *et al.*, 1990). It uses more raw materials and employs more people than any other industrial sectors (Garrahan & Steward, 1992) and is of economic significance to many countries, especially in Germany. In this country alone, about 670.000 people are directly employed in this industry, which has an average yearly turnover of about 200 billion Euro[2]. German OEMs have been very successful the last few years and have been increasing their importance in the global marketplace primarily at the cost of North American and Asian competitors. DaimlerChrysler and Volkswagen not only account for two of the five largest OEMs worldwide, they have (like Porsche and BMW) an excellent reputation and are valued for their comfort, reliability, and quality. The application of modular sourcing has contributed substantially to their success.

The application of modular sourcing is primarily based on the necessity to reduce investments and increase profitability. German OEMs are, compared to their Asian counterparts, less productive (Womack & Jones, 1990) and less profitable, which is primarily related to the disadvantages in production costs. Because of high labour costs, German OEMs are forced to seek alternative ways to lower costs and increase performance. The application of modular sourcing is regarded as an important operating structure in order to achieve these goals. Therefore, the focus on German OEMs provides an ideal setting to study modular sourcing and its effects on manufacturing flexibility. In this light, the following primary research question is posed:

What are the effects of modular sourcing on manufacturing flexibility in an automotive supply chain?

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[2] Source: Verband der Deutschen Automobilindustrie, 2001

The primary objective of this study is to increase the understanding of the relationship between modular sourcing and manufacturing flexibility. This relationship is explored at four selected plants of Volkswagen, DaimlerChrysler, BMW and Porsche. Furthermore, a survey is used to study this relationship and to generalise findings.

In this study manufacturing flexibility is observed as the ability to change or react to changes with little effort, cost or performance (Upton, 1994). In order to derive the effects of modular sourcing of this, different supplier types are defined based on technology, process, product, and market (TPPM) combinations. This classification allows for the identification and comparison of the differences in flexibility achieved in modular sourcing relationships and other (non-modular sourcing) relationships. The difference in flexibility achieved highly depends on the efficiency[3], effectiveness[4] and agility[5] of the supply chain parties. The supply chain viewpoint in this study has a broader scope than logistics management and observes the entire value adding process from the attempt to produce the right inputs, to the effort to convert them into finished goods, and then dispatch them to the final customers (Ellram, 1991).

To help in answering the primary research question, the following secondary questions are defined that focus on the most essential issues:

What moderating and quasi-moderating variables can be identified that influence the relationship between modular sourcing and manufacturing flexibility?

The relationship between modular sourcing and manufacturing flexibility is expected to be influenced by so-called 'moderating' and 'quasi-moderating' variables. Moderating variables directly influence the strength of the relationship between the two research constructs. Quasi moderators are almost identical to (pure) moderators with the difference being that they can be considered as independent variable as well in the studied relationship (Sharma *et al.*, 1981). In other words, quasi-moderating variables may affect the level of flexibility achieved without being related to modular sourcing.

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[3] Includes faster cycle times, tight integration of the R&D and manufacturing processes.

[4] Includes an increased level of control over the supply chain, proactive management of key data, and higher quality sourcing decisions within organisations.

[5] Agility refers to the exploitation of profitable opportunities in a volatile market place caused by better using market knowledge (Naylor *et al.*, 1999).

What dimensions of manufacturing flexibility can be identified and how can they be structured?

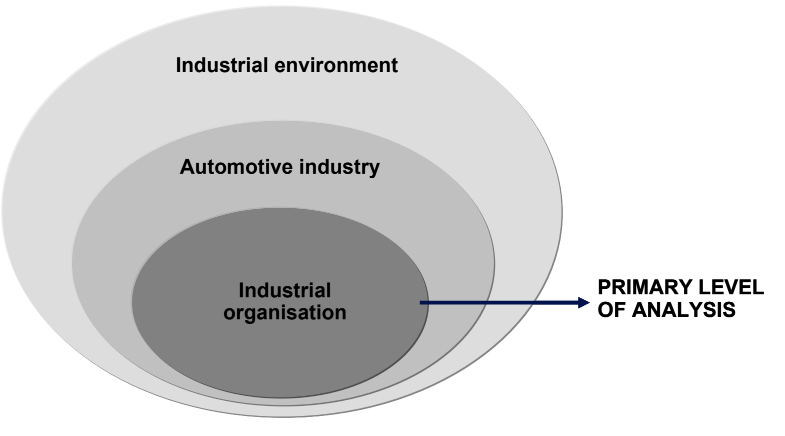
Observing the literature on manufacturing flexibility, many definitions can be found as well as the description of a variety of dimensions. Among the vastness of publications, manufacturing flexibility is widely recognised as a multi-dimensional concept. Based on the analysis of the key publications, key dimensions of manufacturing flexibility are specified that jointly comprise the entire domain. Finally, a hierarchy of these flexibility dimensions is developed in which lower level flexibility dimensions function as building blocks for the higher levels.

How can manufacturing flexibility be measured?

Despite the contributions of available publications, a lack of good generally applicable items and measures exists. The ability to measure manufacturing flexibility is a first step in understanding and then improving it. In this study a multi-item scale is developed for measuring manufacturing flexibility and for validation of the relationship between the research subjects.

In this study three levels of analysis are observed (see figure 1-1). After discussing the unpredictability, uncertainty, and complexity of the industrial environment, the applied business strategies in the automotive industry are addressed. The primary level of analysis in this study is on the industrial organisational level. On this level, the manufacturing system and the achieved level of flexibility is observed.

Figure 1-1: Levels of analysis



The main focus of this study is on the lower hierarchical levels of the developed flexibility hierarchy, which correspond to the micro economic level as depicted in figure 1-1. On a micro level, machine and personnel flexibility are considered basic building block of the hierarchy. These two ‘resources’ support the functional level on which the following five dimensions are observed: process flexibility, volume flexibility, expansion flexibility, logistical flexibility, and product flexibility. At the plant level, manufacturing flexibility is observed as equally important to strategic flexibility as other dimensions such as R&D flexibility, marketing flexibility, and sales flexibility. Based on the analysis of these levels, the effects for strategic management can be derived.

1.3 Research design & structure of the study

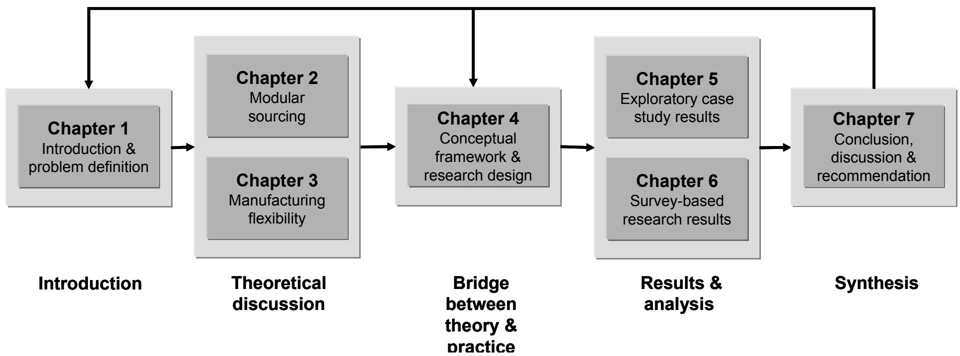
Based on extensive literature research, modular sourcing, as well as manufacturing flexibility, will be analysed and defined. Based on this theoretical part, a preliminary conceptual framework will be developed. Both exploratory case studies and survey-based research will then be used to validate the proposed conceptual framework.

The use of multiple types of research is in alignment with the insights from triangulation. Triangulation is a convergent methodology based on the conception that qualitative and quantitative methods should be viewed as complementary (Yin, 1994). The mix of methods allows the researcher to draw upon the paired strengths of the methods used. In addition to this, Jick (1979) states that the most prevalent use of triangulation is in the efforts to integrate fieldwork and survey methods. The application of multiple methods not only increases the accuracy of the study, but also allows the formulation of more conclusive findings if the applied methods lead to similar conclusions.

Case studies are used to develop a strong feeling for the subject being studied. However, case studies do not lead to statistical generalisations (Yin, 1994). This weakness is partially counterbalanced by the use of survey-based research (Churchill, 1995). Based on the case studies findings, a survey is initiated in order to support the exploratory research findings.

This study is divided into four parts, which are displayed in figure 1-2. In the first part, modular sourcing and manufacturing flexibility are examined in conjunction with the relevant economic theories. Chapters 2 and 3 furthermore provide insight into the developments in the automotive industry, which provides the basis for understanding the potential effects of modular sourcing on manufacturing flexibility. These developments are framed into a so-called ‘structure-conduct-performance’ model that allows a comprehensive view of the relationship between the organisational environment, its behaviour, and performance.

Figure 1-2: Design of the study by chapter



In the second part of this study, a bridge between theory and practice is built. In chapter 4, the exploratory case studies and survey-based research design are discussed that are used to validate the proposed conceptual framework. This chapter discusses the advantages and disadvantages of these research approaches as well as the necessary steps to validate the conceptual framework.

In the third part, the research results are presented. Chapter 5 discusses the exploratory case study findings and propositions made. Furthermore, the moderating variables, as well as the quasi-moderating variables for the relationship between modular sourcing and manufacturing, are highlighted. The survey research results concerning the main research construct are presented in chapter 6.

In the final part of this study, the synthesis between theory and practice takes place. In chapter 7 the answers to the posed research questions given. In the discussion section the research findings are reflected against the available literature. Furthermore, the research strategy in this study is critically reviewed. Finally, the implications for research and management are derived.

1.4 Scientific & societal relevance

The primary objective of this study is to contribute to a better understanding of the relationship between modular sourcing and manufacturing flexibility in the automotive industry. The rationale for the development of a conceptual framework has scientific and societal relevance.

From a scientific point of view, this study provides several theoretical perspectives that will help to clarify the role of manufacturing activities in achieving a competitive advantage. The ‘transaction cost theory’ (e.g. Coase, 1937; Williamson, 1979), and the ‘resource-based view of the firm’ (e.g. Penrose, 1959; Learned *et al.*, 1969; Barney, 1991) are used as the 'economic lens' through which the relationship between modular sourcing and manufacturing flexibility is studied. This study not only contributes to a better understanding of governance choices in the automotive industry, it also argues that technological uncertainty needs to be observed in these choices. The contingency theory (e.g. Woodward, 1965) is used for this argumentation and also provides the basis for defining the process flexibility dimension.

The analysis of the relationship between modular sourcing and manufacturing flexibility has a societal relevance as well. The variety of products in the automotive industry is increasing tremendously. New niche models such as sports utility vehicles (SUVs), multi-purpose vehicles (MVPs), and ‘cross-over’ models are launched in an effort to gain market share and improve profitability. These developments need to be studied from an economic perspective to not only derive industrial implications, but also to obtain insight into the dynamics of the ‘make-or-buy’ decision process. These dynamics are increasingly becoming important in the design of organisational policies, which in turn should support the flexibility of organisations for economic adjustment and industrial innovation (Volberda, 1999).

Furthermore, the studied implications of modular sourcing on manufacturing flexibility provide managers insight in the dangers of outsourcing too many activities. Blindly increasing the level of outsourcing and striving to become a ‘virtual’ organisation may not always be a successful strategy. Finally, the multi-item scale as developed in this study can help practitioners to understand the nature of manufacturing flexibility (including its dimensions) and how this can be measured.

1.5 Research boundaries

There are a number of research boundaries that need to be observed in studying the effects of modular sourcing and manufacturing flexibility.

The ‘economic lens’ in this study is used to analyse modular sourcing and manufacturing flexibility on a micro economic level. These constructs are viewed from a decision-making management level in an effort to strive for continuity.

Manufacturing flexibility can be studied with the focus on ‘actual’ and ‘potential’ flexibility (Koste, 1999). The hypothetical nature of potential flexibility results in measurement difficulties and the possibility of bias in its estimation. Although the study from Upton (1997) found a strong correlation between actual and potential flexibility, care must be taken when interpreting these results. The immediate nature of the findings can be interpreted as a potential that could be achieved the next day (Koste, 1999). Responses to the measurement may reflect the actual levels that were previously achieved, but clarity is lacking. Therefore, in an effort to reduce the possibility of bias, only the actual flexibility is observed in this study.

Because of the cross-functional nature of modular sourcing and manufacturing flexibility, several relevant research fields (e.g. shop-floor design, inbound and outbound logistics) are studied to get a more comprehensive view on the research subjects. These research fields are approached from a supply chain context in which the manufacturing systems of the OEM and supplier are observed. Even though many other aspects could be important to observe from a supply chain context, the main focus is the moderating and quasi-moderating variables that significantly influence the relationship between modular sourcing and manufacturing flexibility.

In this study, flexibility is primarily observed on a micro economical level. On this level are primarily functional (volume, expansion, process, logistics, product) and resource-related (machine and personnel) flexibility dimensions observed. The resulting plant level flexibility in turn influences the strategic flexibility of the organisation. However, the analysis of implications on the strategic level lies beyond the scope of this study.

Finally, the focus on German OEMs is not bounded by geographical locations but is related to management thinking and the design of modular sourcing relationships. All German OEMs discussed have international operations that are designed in alignment with country specifics.

2 Modular sourcing

In recent years there has been an amazing amount of verbiage instructing managers on how to become 'leading edge', 'excellent', or 'innovative' - yet little of it attends to the practical question of to get things done in organisations. To be sure, there has been a lot of hoopla about the 1990's heralding a new era of progressive, non bureaucratic organisations, but these 'New Age' idea's are often propounded in such a way to make their translation into action frustrating or even impossible.

(Eccles & Nohria, 1992, p.1)

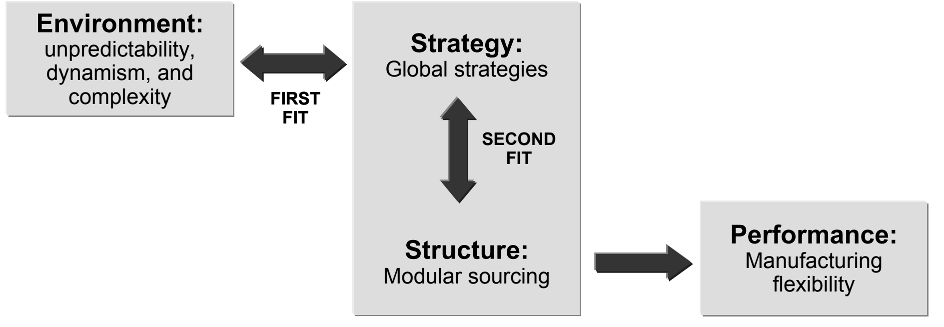
2.1 Introduction

In this chapter the concept of modular sourcing will be analysed and placed in an automotive industrial context. This provides the basis for better understanding the potential effects of modular sourcing on manufacturing flexibility in this industry.

Researchers used to think of organisations in terms of stability, order, and uniformity whereas they now associate them with chaos, creativity and diversity. These changing views in management thinking will be discussed in paragraph 2.2. In order to improve the understanding of the relationship between the organisational environment, its behaviour, and performance, so-called 'structure-conduct-performance' models can be used. These models have their roots in the contingency theory and have been used to study: leadership (e.g. Fiedler, 1967), organisational learning (e.g. Nevis *et al.*, 1995), differential learning styles across hierarchical levels (e.g. Jelink, 1979), and structures of national unions (e.g. Child *et al.*, 1973).

The model of Lawrence & Lorsch (1967) is adopted in this study, since it helpful to discuss the 'fit' between developments in the industrial environments, the organisational strategy, operating structure, and resulting performance. A basic assumption of their so-called "environment-strategy-structure-performance paradigm" is that superior organisational performance stems from two types of 'fit' (figure 2-1). The first 'fit' in the paradigm of Lawrence & Lorsch (1967) is between the organisational strategy and the environment and will be discussed in paragraphs 2.3. In paragraph 2.4 globalising strategies and the effort to gain economies of scope are discussed. The second 'fit' between organisational strategy and modular sourcing as an operating structure, is discussed in paragraph 2.5. Paragraph 2.6 discusses the extent of vertical integration and governance choices. Finally, the most important conclusions of this chapter are summarised in paragraph 2.7.

Figure 2-1: Environment-strategy-structure-performance paradigm



Structure-conduct-performance (SCP) models are important for designing organisational strategies. However, like all theoretical models, some limitations have to be observed. Some of the most important aspects not observed in SCP models are: the impact of incumbent organisations, profit on entry by new organisations, efficiency and effectiveness on new entry (Calton & Perloff, 1994). In addition, the 'Chicago political economy' scholars[6], argue that SCP models are too static and do not observe behavioural issues. These limitations suggest that SCP models cannot be effectively used for strategy development. Therefore, the use of the model developed by Lawrence and Lorsch (1967) in this study is limited to the analysis of modular sourcing.

2.2 Changes in management thinking

From the second half of the nineteenth century till now, major changes have taken place in the European industrial environment that have brought along changes in dominant management thinking. Warnecke (1993) gives an overview of these changes in the industrial environment and describes them in terms of 'industrial

[6] In contrast to the SCP models, the Chicago political economy focuses on the characteristics of the individual organisation instead of the industry. Second, these scholars emphasise the incentives of legal structures imposed on rational, cost- and benefit-calculating organisations and individuals (see Stigler, 1966).

revolutions' which are largely based on the technological progress that was made in manufacturing techniques.

The first industrial revolution was initiated by the introduction of the steam engine that sped-up the production processes and supported the workforce. The development of electric engines and the assembly line in the early 1900's introduced the 'classical mechanising' and the related 'Tayloristic' work approach (Moerman, 1999). Taylor (1947) argued that the 'old' system, where management left it up to the workers to figure out how to get the job done, was very inefficient. In response to traditional management, scientific management combined the physical capabilities of the worker with an economic approach that viewed people as driven by the fear of physical starvation and in search of monetary rewards (Kilmann, 1979). Taylor's aim was to replace the arbitrary and capricious activities of managers with analytical, scientific procedures. Radical product- and process innovations by Henry Ford made skilled craftsmen, who only were able to build complex products, superfluous. This entailed the use of an assembly line that made the production of standardised vehicles possible at lower costs. This standardisation allowed the use of 'single purpose' machines that were able to create scale advantages. Thus the second industrial revolution is characterised by tremendous increases in productivity and efficiency of the production process. The third industrial revolution started with the introduction of automated production in the 1970's. The aim was to further increase productivity and efficiency by using robots for final assembly.

Unlike scientific management, the classical administrative theory (Fayol, 1947) was concerned with the overall design of the organisation. Fayol (1947) argues that specific managerial processes, such as planning, coordinating, and controlling are requirements for efficient and effective task fulfilment. This theory laid the basis for principles such as 'span of control', 'departmentalisation' and 'line-staff'. Even though the classical administrative theory and scientific management had a lasting effect on management practice, it was the classical economic theory that provided intellectual legitimacy for the two former mentioned theories (Volberda, 1999). The classical economic theory has its roots in the ideas of Adam Smith (1776), who described the principles of specialisation in his work "An inquiry into the nature and causes of the wealth of nations". According to Adam Smith, the only purpose of an organisation is to strive for profit maximisation. In the classical management approach, an organisation is regarded as a machine without any environmental influence:

> *"The universe was frequently compared to a hermetically sealed lock… Like a clock, its behaviour was thought to be determined by its internal structure and the causal law of nature (Ackoff, 1981, p. 11)"*

The ideas of scientific management, classical administrative and economic theory provided the ideas and rules for the dominant management thinking of the last century. Yet these theories are not outdated; successful companies such as McDonalds are basically improved extensions of the scientific management principles of division of labour and detailed work procedures since they have perfected a method of delivering standardised products at low costs (Volberda, 1999).

This technical rationalisation has been revised several times since coming under empirical scrutiny and can be found in the modern management approaches. The human relations movement of Elton Mayo (1933) criticised the classical management approach primarily for its lack of consideration of social relations among people in an organisation. The bounded rationality school of Herbert Simon attacked the perfect rationality assumptions and argued that decision- makers have limited reasoning and information processing abilities. In the 1950’s, Douglas McGregor and Chris Argyris developed a model that comprehensively observes the need of the human being and enables a better use of the human capital, often referred to as the human resource school. Finally, the contingency theory of Joan Woodward (1965) laid the basis for the situational structuring of organisations.

The common denominator of these management approaches is the view of organisations as multi-purpose mechanisms designed to achieve specific goals in different environments. The organisation is considered to be an ‘organism’ striving to survive in the environment. In other words, the focus changed from controllability of the organisation to changeability, variability and flexibility. By 1985, Toffler had already observed that traditional methods, organisational structures and routine responses were no longer working properly. Furthermore, the tension between the complexity of the organisation and the environment was becoming more apparent (see paragraph 2.3.2). The increasing organisational complexity was primarily caused by ‘rational thinking’, and technical improvements had a negative effect on organisational flexibility. An empirical study by Steward (1983) provided evidence for the discrepancy between traditional assumptions and actual management behaviour. As a consequence of this shift, rigid classical processes have been replaced by approaches that take developing and maintaining reciprocal relationships into account.

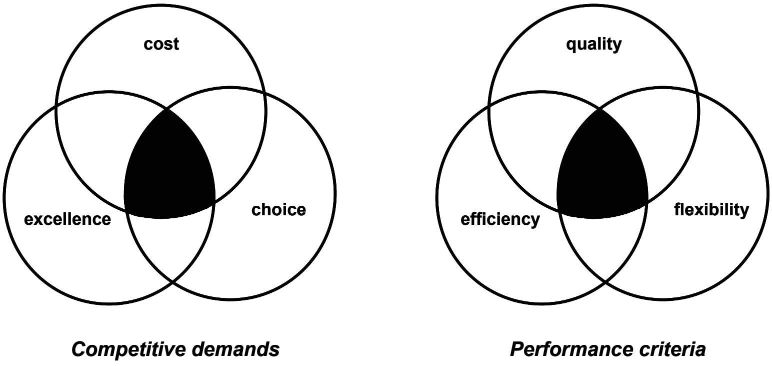
These classical and modern management theories led to the development of industrial organisational models. Moerman (1998) developed a comprehensive contemplation model in which three micro organisational levels are observed. In this model the 'machine' level refers to the type of machines used, whereas the 'production' level is related to the configuration of these machines on the shop floor. Finally, the ‘logistical’ level refers to the in- and outbound flow of goods. These observed levels of the contemplation model for an industrial organisation are the building blocks of the ‘lean production’ approach described by Womack *et al.* (1990).

The idea behind lean production is to use less input to create an output that is similar to the mass production system. In a lean production approach, the supply chain parties jointly identify the value adding activities for each product and try to optimise them. In most cases, cross-functional teams are formed between organisations that focus on eliminating all non-value adding activities and reducing throughput time (Hines, 1994). The pioneer of lean production was Eiji Toyota who, after World War II, was forced to develop a production system that was very different from the mass production system practiced by Henry Ford in the USA. In the 1960’s and 1970’s, it became clear in the West that the Japanese production system was far superior in comparison. Schonberger (1982) concluded that the just-in-time (JIT) principle was one of the most important factors for lean production.

Even though Womack *et al.* (1990) introduced lean production in the 1990’s as ‘the’ production system of the future, it has received quite some criticism. Despite numerous claims that lean production is superior to mass production, some researchers (e.g. Oliver *et al.*, 1994; Lin & Hui, 1999) have raised doubts as to whether this is universally true. Under different market and operating conditions than those found in Japan, it is questionable as to whether the lean system can indeed outperform the mass production system. A study of Oliver *et al.* (1994) provided empirical evidence that Japanese manufacturing systems only perform better than manufacturing systems in the UK when market demands are stable and employee absenteeism is low. In addition, an empirical study of Lin & Hui (1999) provided empirical evidence that a higher performance level in a lean production system is only achieved if there is no time pressure. This discussion illustrates that no consensus has been achieved on the next dominant production design. Mass producers, especially, should have a clear understanding of the environmental turbulence before abandoning their production system and instantly changing to a lean design.

Observing these changes in management thinking, it can be concluded that competitive demands have been increasing. The accumulation of competitive demands and the conflicting performance criteria based on Volberda (1999) is depicted in figure 2-2. First of all, consumer demands proliferate and are communicated to organisations more effectively and vigorously, which characterises the shift from traditional ‘sellers’ to ‘buyers’ markets. Even though organisations often face saturated markets because of overcapacity, customers demand even more choice. Organisations need to offer a variety of products and services in small quantities within ever-shorter delivery times. In addition, they have to cope with variable delivery times, increased product range, fast changing lot sizes, customised products, and sales volume fluctuations.

Figure 2-2: Competitive demands and conflicting performance criteria



According to the generic strategies described by Porter (1980, 1996), organisations should only focus on one competitive demand as depicted in figure 2-2 in order to achieve a sustainable competitive advantage. Porter (1980, 1996) argues that firms that try to pursue dual strategies can become ‘stuck in the middle’, when a technological standard has not been reached. On the other hand, D’Aveni (1994) and Baden-Fuller & Stopford (1994) argue that organisations simultaneously have to compete on multiple competitive demands, and that the emphasis on one criterion can trap an organisation. They argue that in the turbulent market place, organisations are forced to focus on costs, excellence, and choice, and at the same time are under pressure to find new approaches in increasing performance criteria such as flexibility, efficiency, and quality.

2.3 Environmental turbulence

2.3.1 Environmental threats

Several competitive forces can be identified that determine the intensity of the environmental turbulence. Based on the five forces model of Porter (1980), the environmental threats are analysed as a basis for understanding the chosen strategies. The forces in an industrial environment that can threaten to either maintain or create above-normal returns are (1) threat of entry, (2) threat of rivalry, (3) threat of suppliers, (4) threat of substitutes, and (5) threat of buyers.

The (1) threat of entry refers to organisations that have recently begun operations in an industry or market or that threaten to begin operations soon. The extent to which new entrants pose a threat to an incumbent organisation depends on the cost of entry, which in turn depends on the existence and 'height' of barriers to entry (Bain, 1968). Bain (1968) and Porter (1980) described five barriers of entry that should be significant in order to keep new entrants out even though incumbent organisations continue to earn above normal economic rents. The first one, economies of scale, refers to production cost advantages that can be achieved based on volume differences. The second, product differentiation, refers to incumbent organisations that possess brand identification and customer loyalty that potential entrants do not possess. The third, refers a whole range of cost advantages, incumbent organisations may have, independent of economies of scale, such as proprietary technology (Porter, 1980), know-how (Kogut & Zander, 1992), favourable access to materials (Scherer, 1980), favourable geographical location (Ricardo, 1817), and learning curve cost advantages (Scherer, 1980). The fourth, contrived barriers of entry, refer to incumbent organisations that engage in activities whose sole focus is to deter new entry, even if these activities may reduce the efficiency of operations (Tirole, 1988). The fifth refers to trade barriers enforced by governments who, for their own reason, may decide to prevent entry into an industry.

The (2) threat of rivalry refers to the intensity of competition among an organisation's direct competitors. Price competition in a market indicates a high level of rivalry and is often caused by a large number of competing organisations. In effort to reduce operating costs, a consolidation process has been taking place in the automotive industry during the last 40 years[7] resulting in a few large OEMs. Even though the number of competitors has decreased, OEMs now face an increased level of internal (between brands) competition. Despite attempts to position brands and models differently, cannibalisation remains to some extent. Moreover, rivalry tends to be high when industry growth is slow. Even though the competition in luxury vehicle segments has been primarily based on performance and reliability, price reductions have become more common.

The (3) threat of suppliers refers to the ability of suppliers to negatively influence the performance of organisations by increasing prices or by reducing the quality of the goods. Any above normal performance profits can be transferred to suppliers this way. This threat is enhanced if an industry is dominated by a small number of suppliers (Porter, 1980). In addition, suppliers are a greater threat when what they supply is unique and highly differentiated or when suppliers are not threatened by substitutes. Moreover, the threat of suppliers is greater when they are able to vertically integrate forward or when an organisation is not considered an important customer to its suppliers.

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[7] See appendix A for an overview of this consolidation process.

The (4) threat of substitutes and (5) buyers primarily apply to first and second tier suppliers. Substitutes are products or services that meet approximately the same customer needs, but do so in different ways. For instance, simple component suppliers in low wage countries (Eastern Europe and Asia) are able to produce high quality substitutes for products made by Western European suppliers. The threat of buyers is particularly high if the number of buyers is small. In addition, this threat is raised if the products sold are undifferentiated (standard), and represent a significant percentage of a buyer's final costs. Finally, the threat of buyers is high if they are not earning significant economic profits and when they threaten to integrate backwards.

Volberda (1999) states that the structure of the competitive forces as described above is not stable. He argues that these forces are continuously being changed, both consciously by strategic decisions, and as an outcome of the competitive interaction between organisations, and are therefore subjected to turbulence. Khandwall (1977) defines such a turbulent environment as:

> *"… a dynamic, unpredictable, expanding, fluctuating environment in which the competitive forces are marked by change (Khandwall, 1977, p. 333)."*

Emery & Trist (1965) pointed out that this turbulent environment is highly connected to the organisation as well as to change itself. On the other hand, Babüroglu (1988) suggested that complexity plays a major role in observing the industrial environment, yet he especially focuses on the transitional state of turbulent environments. D'Aveni (1994) introduced the concept of 'hyper-competition', which refers to an environment that is characterised by intense and rapid competitive moves in which organisations are forced to move quickly to build advantages and erode the advantages of their competitors.

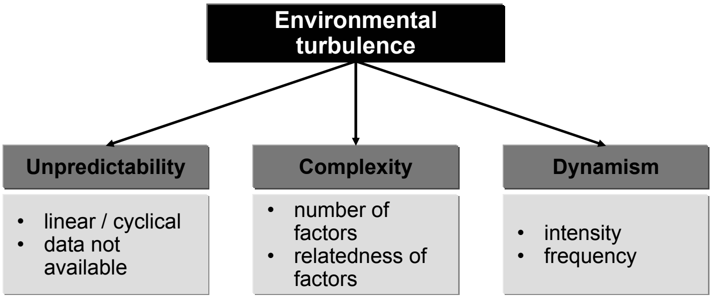
This discussion illustrates the difficulty of grasping the concept of environmental turbulence. In this study, environmental turbulence is considered as an aggregate of various dimensions related to change. A comprehensive classification of environmental turbulence, developed by Volberda (1999), is adopted in this study (see figure 2-3).

The differentiation between predictable-unpredictable, static-dynamic, and simple-complex[8] competitive forces can be universally applied. It should be noted that these dimensions affect environmental turbulence simultaneously. In research on environmental turbulence, unpredictability has received the most attention and is usually considered the ultimate dimension that includes the two other dimensions (Lawrence & Lorsch, 1967). However, Volberda (1999) argues

[8] The complexity is discussed in the next paragraph in more detail.

that it is possible to have highly dynamic and complex environments that are largely predictable. In accordance with Thompson (1967), Volberda (1999) argues that unpredictability reflects the extent to which cause-and-effect relationships concerning competitive forces are incomplete. When transitions of factors within competitive forces are either linear or cyclical, management can extrapolate past developments. However, in most cases, there is a lack of information about the environment. To compensate, the organisation may increase its capacity to process and analyse information, which has the drawback of being inaccurate and uncertain (Eppink, 1978).

Figure 2-3: Dimensions of environmental turbulence



Dynamism is considered a key environmental dimension by several researchers (e.g. Burns & Stalker, 1961; Duncan, 1972). This dimension describes the degree to which the competitive forces remain basically static over time or are in a continuous process of so-called 'dynamic change' (Duncan, 1972). However, most researchers do not distinguish between the rate of environmental change (frequency) and the intensity of the changes. In fact, Burns & Stalker (1962) only focus on the rate of change under specific technological conditions. Similarly, Dill (1958) only emphasises the speed of shifts in environments. It is possible to have fast-occurring changes in the environment with a low intensity. Therefore, both frequency and intensity have to be included in valuing dynamism.

2.3.2 Complexity in the automotive industry

A third factor of influence on environmental turbulence is complexity. This factor has been described by several authors (e.g. Boutellier *et al.*, 1997; Piller & Waringer, 1999) and corresponds to the diversity dimension of Lawrence & Lorsch (1967) and the heterogeneity dimension mentioned by Dill (1958) and Thompson

(1967). In order to determine the extent of complexity, the industrial life cycle needs to be observed. Emerging industries are often formed by the development of new products or technologies that radically alter the rules of the game in an existing industry (Schumpeter, 1934). However, over time, as technologies diffuse through competitors, and the rate of product innovations tends to decline, the industry begins to enter the mature phase. The automotive industry can be characterised as such a mature industry which is reflected by slow growth in total demand, an increase in the amount of international competition, and an overall reduction of OEM profitability.

Porter (1980) suggests that in mature industries, the emphasis should be on refining the existing product range, increasing the quality of service, reducing manufacturing costs and increasing quality through process innovations. In addition, traditional strategies that focus on technology and costs leadership need to be modified. A greater emphasis should be placed on services and process innovations. An organisation that is able to develop a reputation for high-quality customer service may be able to obtain superior performance even though the products sold are not highly differentiated. Similarly, Hayes & Wheelwright (1979) concluded that the role of process innovations designed to reduce costs and increase productivity, become more important over time than product innovations. In a study over seventy vehicle assembly plants, Krafcik & MacDuffie (1989) and Womack *et al.* (1990) concluded that six plants achieved superior performance and were able to simultaneously deliver high quality at low costs. These plants had several things in common; among them was a continuous focus on improving manufacturing processes.

On an industrial level, Bliss (1998) and Piller & Waringer (1999) defined several complexity drivers that influence modular sourcing applications: (1) customer complexity, (2) product program complexity, and (3) manufacturing system complexity.

Changing consumer behaviour and decreasing brand loyalty increase the level of (1) customer complexity. As a result, customer segmentation has become increasingly difficult for OEMs. For example, Volkswagen increased the number of customer segments from nine in 1987 to thirty in 2000 to capture the increasing heterogeneous customer preferences. Furthermore, OEMs are additionally developing niche models for these segments to compensate for volume losses in the main markets.

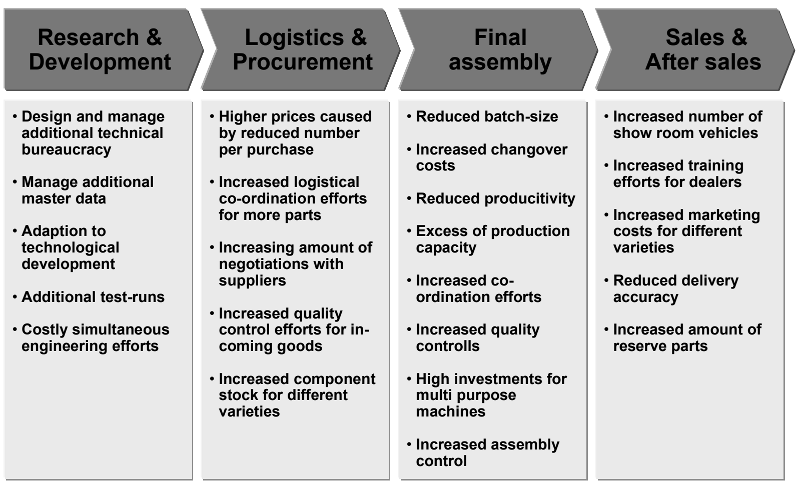
In pursuing this niche strategy, the complexity of the (2) product program increases substantially as well. The increasing variety of product offerings refers to both the number of vehicle models as well as the variety per vehicle model. As a result, the production costs usually rise between 20%-30% when the variety is doubled (Adam, 1997). The lack of ability to transfer existing components to new vehicle models is the primary cause of these increases in costs. Many components needed for the increased variety are often newly developed, even though the available parts could be used with minimal changes. In addition, Clark & Fujimoto (1992) concluded that in the European automotive industry, about 74% of the parts used in new vehicle models are newly developed.

Because the complexity of the product program rises, the manufacturing system complexity (3) is increased as well. A larger number of product varieties result in a decrease of the average batch size. Moreover, this increased level of complexity can lead to discontinuities in the material flow (Piller & Waringer, 1999). Applied ‘flexible’ manufacturing system to deal with the increased level of complexity often show errors and do not deliver the expected flexibility (Upton, 1995; Eversheim *et al.*, 1998; Koste, 1999).

OEMs that offer a large variety of products are confronted with a broad range of customers, operate in variety of distinct markets and geographical areas, deal with many suppliers and different technologies. In this heterogeneous environment, OEMs not only have to observe many factors, but also be aware of their interrelatedness. Moreover, the interdependencies between the factors are not linearly correlated and therefore prohibit ceteris-paribus premises that would enable a separate observation of a specific complexity driver. Therefore, a quantification of the level of complexity is considered difficult among researchers (Adam & Johannwill, 1998; Piller & Waringer, 1999).

Despite the difficulty to grasp single complexity drivers, the effects on a micro level can be depicted along a simplified process (see figure 2-4). The compilation of these effects is based on empirical research conducted by Homburg & Daum (1997), Bliss (1998), and Piller & Waringer (1999).

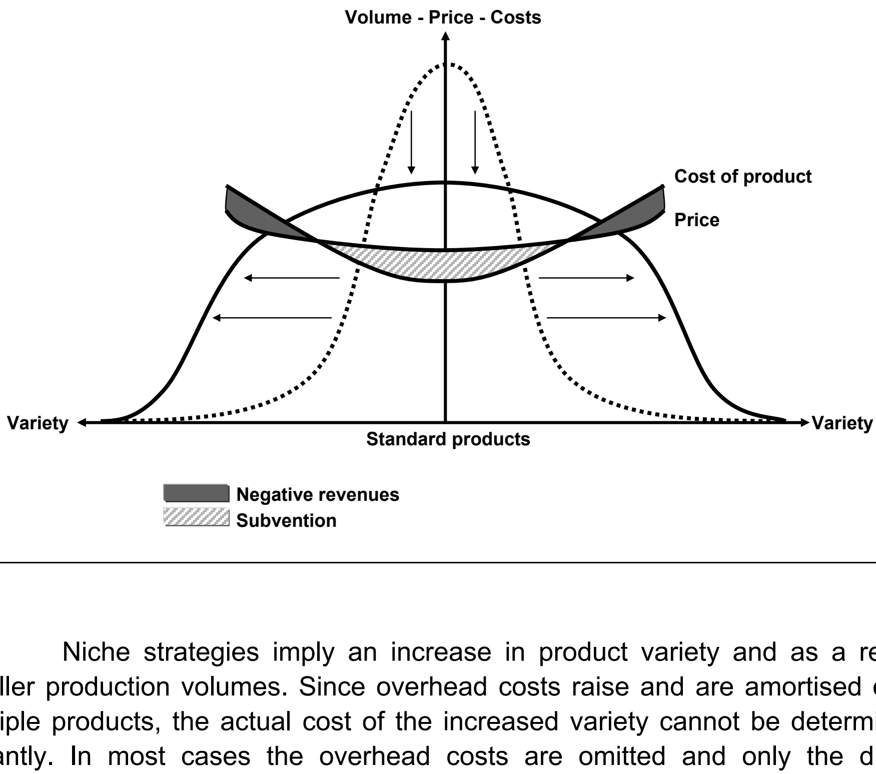
Figure 2-4: Effects of complexity on an industrial organisational level



As can be derived from figure 2-4, an increased level of complexity affects all high-level processes in an organisation and results in higher costs. After an empirical study, Rommel *et al.* (1993) concluded that about 20% of the difference in global production costs are based on geographical factors (wage, material and capital cost), whereas different levels of complexity cause 80% of this difference. Complexity costs are primarily variable costs that rise when an additional product variety is added to the existing range of offerings.

Pursuing niche strategies not only raises complexity and related costs, but can also represent a threat to organisations. This danger is primarily caused by a time-delay between the emergence of complexity related costs and the visible effects, which can be explained by the 'complexity trap' model as developed by Boutellier *et al.* (1997) (see figure 2-5).

Figure 2-5: Complexity trap



Niche strategies imply an increase in product variety and as a result smaller production volumes. Since overhead costs raise and are amortised over multiple products, the actual cost of the increased variety cannot be determined instantly. In most cases the overhead costs are omitted and only the direct development costs are considered as the 'actual' costs of the increased variety.

Niche products are sold at higher prices (because of premium positioning) than the standard products, but below their actual costs (if there was no time-delay). In other words, standard products make up the largest part of the organisation's revenues and are 'used' to subvention the niche products resulting in reduced overall revenues. After a certain time period, the effects of the increased complexity can be determined more precisely. This often results in a price raise for the standard products that in turn may negatively affect the competitive position of the OEM.

Even though the increased product variety may negatively affect revenues, it is a vital part of the OEMs strategies. Only if an organisation is unable to increase the revenues with a larger product variety, is the risk of entrapment high. Therefore, an organisation should focus on reducing the extent of complexity as far as possible and controlling the remaining complexity. The application of modular sourcing can reduce the level of complexity for the OEM and therefore can be a basis for increasing revenues. On the other hand, a higher the extent of outsourcing increases the dependence on module suppliers, which in turn could result in higher prices and negatively affect the organisations' revenues.

2.4 Differentiation and global strategies

2.4.1 Economic value of differentiation strategies

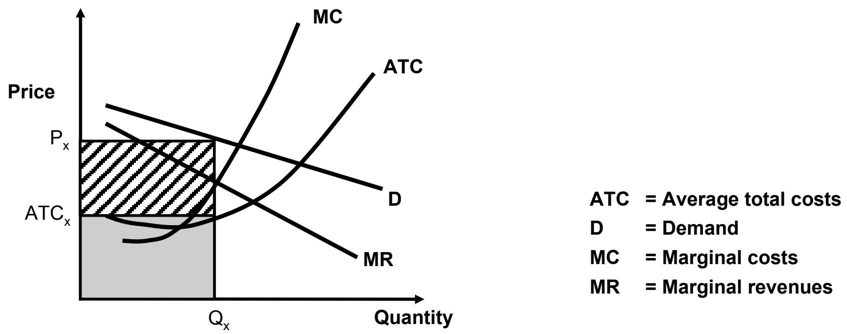
Understanding the environmental turbulence and the effects it has on the strengths and weaknesses of the organisation, is an important precondition for strategic choice and action. Paragraph 2.4.1 examines the differentiation strategy that the selected OEMs primarily pursue. In paragraph 2.4.2 the economic value of global strategies is discussed. The shift in attention from actions taken within a single market or industry to leveraging resources and capabilities across several markets is discussed in paragraph 2.4.3. It should be noted that a differentiation strategy and global strategy can be simultaneously applied and are considered as complementary.

Product differentiation is always a matter of customer perception. Organisations can take a variety of actions to influence these perceptions. First of all, changing the vehicle features is the most obvious aspect that is facilitated by the use of a modular product structure (Sanchez, 1998). Secondly, the introduction of vehicles in the market place at the right time can help in the differentiation efforts. Furthermore, the possible results from first moving can create the perception that the products are more valuable (Lieberman & Montgomery, 1988). Second, reputation is another powerful basis for a differentiation strategy, yet are very difficult to develop. However, once developed, they tend to last a long time, even if the basis for a certain reputation no longer exists (Klein & Leffler, 1981). Third, products are differentiated in the extent to which they are customised for particular customer applications (Pine, 1993;

Lampel & Mintzberg, 1996). The level of customisation can be increased by the use of modular product architectures in combination with platforms. Fourth, increasing the level of service and support associated with a product can be a differentiating factor as well (Anderson & Narus, 1995).

In order to generate a competitive advantage the basis of the differentiation upon which an organisation competes must be valuable. Economically valuable bases enable an organisation to increase revenues and profit. Given the variety of ways in which organisations can differentiate their products, it is logical that the impact of this strategy has been studied extensively. Figure 2-6 describes the value of a product differentiation strategy and is based on Chamberlin, (1933).

Figure 2-6: Value of a product differentiation strategy



When organisations sell differentiated products, they have the ability to use different price levels, which is reflected by a downward sloping demand (D). In other words, an organisation can sell its product at very low prices and produce a relatively large output, or vice versa. Selling differentiated products and having a downward sloping demand curve indicates a monopolistic competitive situation. In such a situation organisations can maximise their profit by ensuring that the marginal revenues (MR) equal the marginal costs (MC). The average total cost curve (ATC) can have a variety of shapes that depend on factors such as the cost of product and economies of scale.

In order to maximise profit, the organisation produces an amount (Q_x) such that the marginal costs equal the marginal revenues. This amount is sold at a certain price level (P_x), which height depends on the downward sloping demand curve (D). As can be derived from figure 2-6, the average total cost (ATC) is lower which results in an above-normal economic profit, which is indicated by the crosshatched section.

Under the assumptions of perfect competition, the existence of an above normal economic profit motivates the entry into such a market (Chamberlin, 1933; Robinson, 1934). As a result, the demand curve facing incumbent organisations would shift downward and to the left. This implies that customers of the incumbent organisation will buy less of its output if the prices are maintained, or that an organisation will have to lower its prices to maintain the current volume of sales. Barney (2001) notes that if in the long run, entry into such a market can result in a situation in which the marginal costs equals marginal revenues exactly and have the same average total cost level. The ability of the organisation to market differentiated products, and obtain above normal economic profits, depends on the rarity and inimitability of the organisational strengths and weaknesses. Furthermore, successful differentiation strategies help organisations to respond to the environmental threats as described in paragraph 2.3.1.

Product differentiation reduces the threat of entry since potential entrants are forced to not only absorb the standard costs of entry but also additional costs for building a customer base. In other words, the additional costs associated with overcoming incumbent organisations' product differentiation advantages may be very high. Second, the threat of rivalry may be reduced since each organisation in the automotive industry tries to carve out its own unique product niche. This does not imply that this threat is eliminated since these products still compete with one another for a common customer segment. However, Porter (1980) notes that the competition is somewhat attenuated, because the customers each organisation seeks are somewhat different. Third, the threat of suppliers can be reduced by a product differentiation strategy as well. Powerful suppliers can raise the prices of the products. These increased supply costs are passed on in the supply chain in the form of higher customer prices. An organisation with highly differentiated products may have loyal customers or customers who are unable to purchase similar products from other firms. These customers are likely to accept increased prices due to an organisation passing on these increased costs. On the other hand, an organisation without a highly differentiated product may find it difficult in pass its increased costs on to its customers since they are able to purchase similar products from a competitor. Fourth, product differentiation helps organisations to reduce the threat of substitutes by making an organisation's current products offerings appear more attractive than substitute products. Finally, the treat of buyers can be reduced in a differentiation strategy as well. Both Chamberlin (1933) and Robinson (1934) described that when organisations sells highly differentiated products, it enjoys a quasi-monopoly in that market segment. Buyers interested in purchasing a particular product have to do buy this from a particular organisation. Any potential buyer power is reduced by the ability of a firm to withhold highly valued products from a buyer.

In a mature automotive industry, product differentiation efforts often switch from attempts to introduce radical technological advancements to product refinements as a basis for product differentiation. Finally, a product differentiation strategy can significantly impact a global strategy (see paragraph 2.4.2) of an organisation. Product differentiation requires an OEM to be in close contact with its customers in order to understand idiosyncratic needs. Global strategies make it relatively difficult for an OEM to differentiate its products in ways that are needed in local markets. As will be discussed in paragraph 2.4.3, an international strategy, where different market segments throughout the world are serviced by quasi-independent operating divisions, may enable an organisation to differentiate its products in ways that respond to local market needs (van Hoek, 1998).

2.4.2 Economic value of global strategies

Global strategies are pursued by almost all OEMs and are often referred to as 'leveraging' strategies. To be economically valuable, they must exploit real economies of scope, and it must be costly for investors to realise these economies of scope on their own (Barney, 2001). The chosen strategy must enable OEMs to exploit environmental opportunities or neutralise its threats.

Economies of scope exist because of the cost savings or revenue enhancement that the OEM experiences because of the mix of business in which it operates. Barney (2001) differentiates several potential sources of economies of scope. In pursuing global strategies the organisation can (1) gain access to new customers, (2) gain access to low cost production factors, (3) develop new core competencies, (4) leverage current core competencies in new ways, and (5) manage corporate risk.

The most obvious economy of scope that motivates organisations to pursue a global strategy is the potential (1) new customers for products that such a strategy might generate. Gaining access to these customers can also help an organisation manage changes in domestic demand as its products evolve through different stages of their life cycle[9]. Moreover, gaining access to new customers can increase the production volume. If the production process is sensitive to economies of scale, the increased sales can reduce production costs. In other words, as the volume of production increases, the average cost per unit

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[9] A product can be at different stages of its life cycle in different countries. Therefore, an organisation can use capabilities and resources it developed during a particular stage of the life cycle in its domestic market during the same stage in other markets (Barney, 2001).

decreases until some optimal production volume is reached, after which the average costs per unit begins to rise because of diseconomies of scale. One of the most important sources of economies of scale is the ability to use highly specialised machines that are too costly for small production volumes. Secondly, high production volumes may allow the OEM to build larger manufacturing operations. This link is particularly important is particularly important for continuous process or mass production industries. Third, large production volumes are often associated with higher levels of employee specialisation (Scherer, 1980). As employees specialise in accomplishing a narrow task, they can become more efficient at this task, thereby reducing the operational costs. Fourth, an organisation with a larger production volume can amortise overhead costs over more unit thereby reducing the costs per unit. Many publications have appeared that point out the potential of international operations to generate scale cost advantages (e.g. Fayerweather, 1969; Hout *et al.*, 1982; Barney, 2001). Most of these authors recognise that the realisation of economies of scale requires a high degree of integration across organisational borders. This integration must be focused on those aspects where these economies can be realised. Empirical research by Kobrin (1991) suggests that the most likely sources of these economies cannot only be found in manufacturing operations, as described above, but also in R&D and marketing. Investments in these areas can be amortised over a large sales volume.

Gaining access to (2) low cost production factors (technology, materials, labour) is another important economy of scope for globalising OEMs. Japanese organisations traditionally have tried to gain access to technology by partnering with non-Japanese organisations. While western organisations have often been looking to gain access to new customers in Japan, the Japanese organisations have used this to gain access to foreign technology (Osborn & Baughn, 1987). Of course, the use of a global strategy to gain access to technology is not limited to Japanese organisations. In a publication by Hamel (1991) a Japanese manager is cited, who argues that the strategic alliance with his European strategic alliance partner is only a short-term engagement since this partner is only interested to get mass production technology. Gaining access to low cost materials and labour are traditional reasons for organisations pursuing a globalisation strategy. For instance, suppliers source or produce simple components such as valves and switches in Eastern Europe and Asia because of lower material and labour costs. Many OEMs have set-up production facilities in these areas to gain the advantages of low labour costs. General Motors, DaimlerChrysler, Volkswagen, Audi, and BMW operate automobile assembly plants in countries such as China, Vietnam, and Mexico. While gaining access to low-cost labour is an important determinant for globalisation efforts, the access itself is usually not sufficient to motivate entry a specific country. Relative labour costs can change over time.

Furthermore, low labour costs are not beneficial if the workforce is not able to produce high-quality products efficiently.

The wish to develop (3) new core competencies is another compelling reason organisations implement global strategies. By exposing competencies in new competitive contexts, traditional competencies can be modified, and new competencies can be developed (Barney, 2001). Once these new competencies are developed, they must be exploited to realise their full economic potential. In an empirical study, Hamel (1991) investigated international strategic alliances in order to understand why some organisations were able to learn from their global operations, modify their core competencies, and develop new competencies, while others were not. Hamel (1991) identified the intent to learn, the transparency of business partners, and receptivity to learnings as determinants of the organisation's ability to learn from its global operations.

Furthermore, organisations that can (4) leverage their core competencies across multiple businesses (e.g. by implementing organisational structures, control systems, and compensation policies) will be able to reap economies of scope. This capability is related to using global operations to gain access to new customers as discussed earlier in this paragraph. When organisations gain this access, they often leverage their core competencies across boundaries. When these competencies are leveraged in new ways, they not only extend operations across countries, but are also leveraged in the domestic market that otherwise would not have been economically feasible.

In a globalising strategy, the (5) value for risk reduction is high. Even though diversified operations across businesses are imperfectly correlated with cash flows, the risks can be managed more efficiently (Copeland & Weston, 1983). However, caution should be taken in this argumentation. Some empirical evidence suggests that barriers to international capital flow exist (Adler & Dumas, 1983). These barriers to capital flow lead investors to hold more domestic stocks in their portfolio than they would hold if they were able (at low cost) to hold a worldwide market portfolio (Lessard, 1976). On the other hand, empirical evidence exists as well suggesting that a globalising strategy can benefit shareholders, despite these barriers to capital flow (Severn, 1974). Barney (2001) argues that these barriers to capital flow across countries are, at least, not stable. Over time, when the level of economic integration is increased these barriers are likely to be reduced, therefore positively affecting the reduction of organisational risk.

Overall, research on the economic consequences of global strategies is mixed. Rugman (1979) and Grant (1987) found that the performance of organisations pursuing global strategies is superior to organisations performing only in domestic markets. However, most of this research has not examined the particular economies of scope that the organisations were attempting to realise through a globalisation strategy (Barney, 2001). Other researchers, such as

Brewer (1981) and Michel & Shaked (1986), have attempted to evaluate the impact of global strategies on organisational performance by using accounting measures. These researchers found that the risk-adjusted performance of organisations pursuing a global strategy is not different from domestically oriented strategies. Barney (2001) argues that these ambivalent findings are not surprising since the value of global strategies depends on whether the organisation pursues valuable economies of scope. In addition, the latter mentioned studies failed to examine the economies of scope that the globalisation strategy might be based upon.

2.4.3 Global strategies & local responsiveness

In pursuing the economies of scope as described above, organisations face a constant trade-off between the advantages of responsiveness to market conditions and the integration of their activities across multiple markets. This trade-off is often referred to as the 'global-local dilemma'.

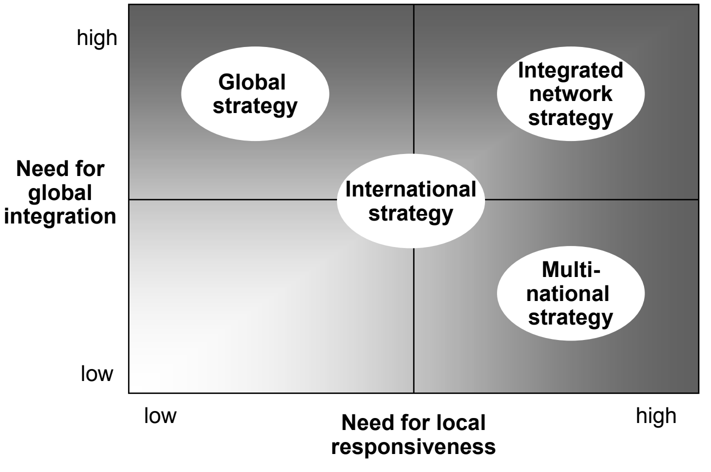
Local responsiveness can help OEMs and suppliers to be successful in addressing the local needs of customers, thereby increasing the demand for the current products. Moreover, local responsiveness enables an organisation to expose its traditional core competencies to new competitive situations. This, in turn, will increase the chance that these core competencies will be improved or will be augmented by new core competencies.

However, local responsiveness comes at a cost. Organisations that emphasise local responsiveness are often unable to realise the full value of the economies of scope and scale that they could realise if their operations across countries were more integrated (van Hoek, 1998). The full exploitation of economies of scale that can be created by selling products in a non-domestic market can only be possible if there is a tight integration across all markets in which a globalising organisation operates. Gaining access to low-cost production factors can not only help an organisation succeed in a non-domestic market, but also helps it succeed in all its markets – as long as those factors of production are used by many parts of the global organisation (Barney, 2001). Developing new core competencies and using the traditional ones can be beneficial in a particular non-domestic market. However, the full value of these economies of scope is realised only when they are transferred from this particular non-domestic market into the operations of an organisation in all of its other markets.

One of the costs of locating different business functions and activities in different locations (e.g. manufacturing in low wage countries) is coordinating and integrating these functions. To ensure that the different operations in a globalising organisation are appropriately coordinated, these organisations typically manufacture more standardised products. Levitt (1983) argues that the homogenisation of consumer preferences allows standardised products to be marketed worldwide. Others, such as Lipman (1988), state that this argument somewhat overstates the case for such homogenisation and most organisations combine or blend local variation with global standardisation. This combination is successful for many organisations when products are modified just enough to make them strong competitors in local markets, but at the same time maintain whatever uniformity is possible across multiple markets to allow some economies of scales to be realised (Batra *et al.*, 1996).

In his study on postponement strategies[10], van Hoek (1998) describes what business strategies may be appropriate to used considering the trade-off between global integration and local responsiveness based on Bartlett & Ghoshal (1989) and Ghoshal & Nohria (1993) (see figure 2-7).

Figure 2-7: Appropriate business strategies



Whereas organisations pursuing a multi-national strategy operate in countries or regions in an independent manner, those pursuing global strategies seek to optimise production and distribution throughout the world by addressing all markets in which they operate (Bartlett & Ghoshal, 1989). The global strategy is characterised by standardisation of products and capital-intensive manufacturing

[10] In a postponement strategy the final assembly of a product is delayed until a customer order is received.

plants (Yip, 1989). In a business environment where both forces of local responsiveness and global integration are relatively low, there will hardly be any drivers for a global strategy formation. Van Hoek (1998) suggested that in these situations, the positioning of the international strategy should be in the middle of the four segments to allow local operations to choose from a variety of processes and products that can be altered minimally to suit local conditions.

The suggested integrated network strategy[11] is comparable to the transnational strategy Bartlett & Ghoshal (1989) described. In this strategy, global operations are treated as an integrated network of distributed and interdependent resources and capabilities. In this context, national operations are not simply independent activities attempting to respond to local market needs; they are also repositories of ideas and technologies the organisation might be able to use and apply in its other global operations (Barney, 2001). When an organisation in one country is able to develop a competence in manufacturing activities, it can be used for operations in other countries. This way, local responsiveness is retained, as country plant managers constantly search for new competencies, and global integration (and corresponding economies) is realised as learnings of plant operations can be distributed to other plants in the global production network.

2.5 Modular sourcing as operating structure

2.5.1 Modular sourcing analysed & defined

Since the first publication in the 1960's on the principle of modularity, many others have appeared that highlight a variety of aspects such as: product, market, classifications, and supply chain relationships. Table 2-1 provides an overview of key publications that are sorted by topic and the aspects of technology, product, and market (TPPM) they highlight.

The publication of Starr (1965) was one of the first that conceptualised the potential of modularity on the product level. Modularity was described as a means that could create 'real variety' beyond the 'apparent variety' that the marketing function was able to create. However, manufacturing systems by that time were not able to generate as much 'real' variety as the market was able to absorb because the necessary technology was not available. Since then, other publications have described the importance of modularity in customisation

[11] See Miles & Snow (1994), Commandeur (1994) and Wildemann (1998a).

strategies (Pine, 1993; Lee, 1998; Piller, 1998) as well as postponement strategies (van Hoek, 1998).

Table 2-1: Overview of publications

TOPIC	KEY PUBLICATIONS	TPPM ASPECT(S)
Strategy, conceptual	Starr (1965); Pine (1993); Lee (1998); van Hoek (1998); Piller (1998)	Product, market
Product architectures, platforms	Abernathy & Utterback (1978); Ulrich & Tung (1991); Mayer (1993); Schindele (1996); Baldwin & Clark (1997, 2000); Wheelwright & Clark (1992); Dudenhöffer (1997); Meyer (1997); Meyer & Lehnerd (1997); Wilhelm (1997); Cusumano & Nobeoka (1998); Robertson & Ulrich (1998); Sanchez (1998); Sawhney (1998); Piller & Waringer (1999)	Process, technology
Supply chain relationships	Sabel *et al.* (1991); Eicke & Femerling (1991); Schraysshuen (1992); Wolters (1995); Wildemann (1996)	Technology
Manufacturing process	Corsten & Will (1995); MacDuffie (1995) Kinutani (1997); Shimokawa *et al.* (1997)	Technology

Publications by Abernathy & Utterback (1978), Ulrich & Tung (1991), Mayer (1993), and Baldwin & Clark (1997, 2000) offer different classifications of product modularity. These classifications range from simple forms, without really changing the nature of what is being produced, to those that enable individual customisation and fundamentally change the design of products. Despite these attempt to structure the different levels of modularity, a lot of confusion remains concerning the definition of modules. Wheelwright & Clark (1992) Robertson (1995); Dudenhöffer (1997), Meyer & Lehnerd (1997), Wilhelm (1997), Cusumano & Nobeoka (1998), Piller & Waringer (1999), Robertson & Ulrich (1998), Sanchez (1998), and Sawhney (1998) primarily discuss the role of modular product architectures in conjunction with technological advancements and product platforms. These publications generally argue that a modular product design should be based on a product platform, since standardised modules can be exchanged between product families at low costs.

Publications by Sabel *et al*. (1991), Eicke & Femerling (1991), Schraysshuen (1992), Wolters (1995), and Wildemann (1996) discuss modularity in relation to supply chain relationships and its dynamics. In the automotive industry, a shift from multiple sourcing towards single sourcing has been taking place. This development is primarily related to the application of modular sourcing and the reduction of the extent of vertical integration.

Shop floor related publications by Corsten & Will (1995), MacDuffie (1995), Kinutani (1997), and Shimokawa *et al.* (1997) observe the concept of modularity in relation to manufacturing processes. These publications discuss the different process choices and the corresponding shop floor layouts. Observing these publications it becomes apparent that the automotive industry has not reached a consensus on a dominant process design and corresponding layout for vehicle assembly. Based on an overview of processes applied in the automotive industry by Shimokawa *et al.* (1997), Kinutani (1997) made a first step in linking the extent of automation in a manufacturing system to the extent of process modularisation.

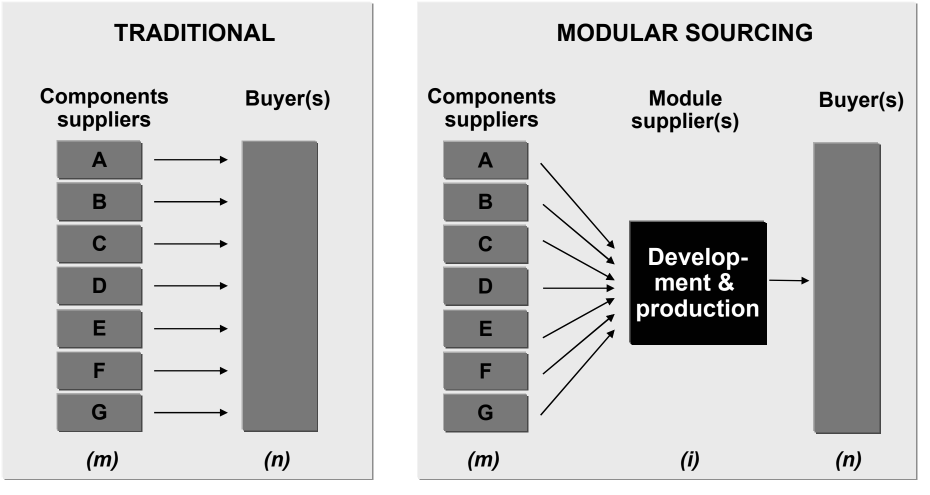
Observing these key publications, it can be concluded that a great number of topics are addressed that help in understanding the concept of modularity. Furthermore, the basis for modular sourcing applications is the use of a modular vehicle architecture and product platform that needs to be defined. The principles of modular product architectures were introduced by Abernathy and Utterback (1978) and were further developed by other researchers as listed in table 2-1. Robertson & Ulrich (1998) refer to product architectures as the scheme by which the function of the product is allocated to the physical component. Product architectures may show two extreme configurations: modularity and integrity. The former, predicates a simple mapping of between functions and components (one-to-one-mapping) and standardised / decoupled interfaces between modules. In contrast, integrity refers to the situation in which complex mapping of functions is displayed and interfaces between components are coupled and not standardised.

For the purpose of this study, it is sufficient to choose a product platform definition which is generic enough to encompass most of the important elements that arise from adoption of a product platform definition. Hence, in accordance with Meyer (1997) it is assumed that a product platform is a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced. The product architecture influences the possibility of applying a platform approach in product development. Muffatto & Roveda (1998) highlighted how product architecture constrains the platform adoption along the product development process. In particular a high level of architectural complexity prevents the communisation of a platform across a family of products. In addition, an increased level of modularity is proved to be beneficial in managing the trade-off between distinctiveness and communality in a product set (Robertson & Ulrich, 1998).

Product differentiation strategies, based on product families sharing a common platform have proved to be successful in the automotive as well as other industries (e.g. domestic appliance, electronics). First of all, the speed in product development is increased. Wheelwright & Clark (1992) described the importance of a long term planning for product development based on the identification of robust platforms allowing fast product upgrades and enhancements. This enables organisations to bridge the technological gap with competitors or provides the basis for a competitive advantage. Second, the development costs are reduced, since they can be amortised over multiple product models. However, a platform approach may not always be successful. In some cases there are heavy constraints on platform definitions depending on the product architecture.

The decomposition of a vehicle into standardised modules enables the separate development of these individual modules by specialised third parties (see figure 2-8).

Figure 2-8: Principle of modular sourcing



These parties are only bounded in their development by pre-defined interfaces that describe the relationship between separated modules. The decoupling of development and production enables the OEMs to reduce the complexity by transferring them to lower level pre-assembly stages. This entails the development of single sourcing relationships between OEMs and several module suppliers as opposed to traditional multiple relationships[12]. Depending on

[12] In the traditional situation m*n relationships need to be managed. In the case of modular sourcing (m+n)*i relationships represent significantly less coordination efforts.

their core competences, OEMs are involved to some extent in the development of a particular module. In other words, even though the number of supplier relations has been decreasing, the intensity of cooperation between the supply chain parties has been increasing. Both OEMs and module supplier profit from a (temporary) shared investment in resources and knowledge development. In other words, the innovation in module supplier relationships has increased compared to the traditional situation. It is important to observe that the application of modular sourcing does not reduce the level of complexity from a supply chain perspective, but merely transfers it to the lower level pre-assembly stages.

The disconnection of module and vehicle assembly reduces complexity for the OEM and increases controllability, which in turn enhances the flexibility of the manufacturing system. Furthermore, modular sourcing reduces the complexity related to the procurement process since fewer supplier relations need to be managed, which reduces overhead costs (Eicke & Femerling, 1991; Fieten, 1991). Finally, the costs for quality control are reduced, since the quality control at the OEM is often omitted for modules. Based on this discussion, the following definition of modular sourcing is offered as a basis for discussing this relationship between modular sourcing and manufacturing flexibility:

> ***"Modular sourcing involves the outsourcing of the design and production of complex components in order to reduce complexity and related costs."***

2.5.2 Module suppliers

In this paragraph three supplier types will be characterised that will be used for the analysis of the effects of modular sourcing on manufacturing flexibility in chapters 5 and 6. For this study, a classification is developed in which technology, process, product, and market combinations (TPPM) are observed (see table 2-2).

The use of TPPM combinations is based on the assumption that every component or module sold has gone through the process of: need identification, the search for the appropriate technology, the design of adequate processes, and finding the right product-market mix. These TPPM combinations are highly interrelated: the development of a base technology for instance has direct consequences for process design and competitive market positioning.

Table 2-2: Classification of suppliers

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
	TECHNOLOGY		
Competence	Process know-how	Development know-how	Process and development know-how
Technological lifecycle	Existing technology	Existing technology / new technology	New technology / new technology
Development of base technology	No	No	Yes, at own risk
Investments	+ / ++	++	+++
Problem solving ability	+	++	+++
Product development	Sometimes	Yes	Yes
Logistical capabilities	+ / ++	++	+++
JIT / JIT variations	JIT	JIT	JIT / JIS[13]
Identification of products	Scanning on the box level	Scanning on the box level	Scanning on module level
	PROCESS		
Process technology	Simple assembly	Assembly	Assembly
Process integration / synchronisation	++	+++	+++
	PRODUCT		
Type of product	Component	Component	Module / system
Value of component	+	++	+++
Functional changeability	+	++	+++
Process integration	+	++	+++
	MARKET		
Competitive scope	Concentration / multiple industries	Concentration	Concentration
Position in hierarchy	First tier / second tier	First tier	First tier
Primary client(s)	Main supplier / module supplier	OEM	OEM
Vertical cooperation	Production	Production and development	Production and development
Intensity of cooperation	+	++	+++
Single sourcing / multiple sourcing	Multiple sourcing	Single sourcing (with change option)	Single sourcing (with change option)
Mutual dependence	+	++	+++
Manufacturing strategy	Local efficiency	Global efficiency	Global efficiency
Worldwide presence	No	Yes	Yes
International production network	No	Yes	Yes

[13] JIS = just-in-sequence: this refers to the just-in-time supply of goods that additionally have the right sequence for building in.

A typical ‘co-supplier’ as characterised in table 2-2 possesses a high level of process know-how and invests in this development. Superior process know-how is the basis for achieving a competitive advantage for this supplier. This type of supplier primarily aims to develop the capability of ‘customer-oriented assembly segmentation’. This capability refers to the optimal use of production capacity and enables the efficient production of heterogeneous products for multiple clients. These suppliers try to gain advantages by reducing their costs below those of competitors. It should be noted that the technology-based cost advantages observed are independent of scale cost advantages. The differences in technology used for processes can create cost differences even when the co-suppliers in question are approximately the same size in terms of production volume. The concept of technology can also be extended to include not just the physical tools used but any process within an organisation used this way (Miles, 1980). A ‘main supplier’ is often chosen to decouple the successive development and production of components. This type of supplier has a high development competence and is primarily involved in the conceptualisation of solution for future vehicle models. This supplier has an adequate level of process know-how, yet superior product know-how is the basis for achieving a competitive advantage. A typical ‘module supplier’ offers problem-solving competencies and has a high level of process and product know-how. In contrast to co- and main suppliers, module suppliers are more independent and often develop ‘base’ technologies at their own risk. Moreover, module suppliers even develop new products without a specific problem definition of a buyer.

In some publications (Eversheim & Schuh, 1993; Wolters, 1995; Wildemann, 1996) similar typologies have appeared. Moreover, these publications extensively described several ways for co-suppliers to become a module supplier. It should be noted that even though the analysis of this process is valuable for understanding the difficulties that have to be overcome, it is not necessarily a particular evolution. This change can be abrupt as well, especially when an organisation is vertically integrated.

Both main and module suppliers try to gain a competitive advantage by increasing the perceived value of their products relative to the ones of the competitors. In other words, these supplier types follow a differentiation strategy (see paragraph 2.4.1). Moreover, these supplier types have recognised that they can maintain or improve economic performance not by competing with all suppliers in their industry but by cooperating with at least some of them. It should be noted that although organisations pursuing cooperative business strategies may be willing to collaborate with each other, this can have important competitive implications. Instead of individual organisations trying to beat out other individual organisations (as in competitive business strategies) competition unfolds between sets of cooperating organisations. Based on Barney (2001) two major types of cooperative supplier business strategies can be identified: tacit collusion and strategic alliances. Suppliers pursuing tacit collusion strategies seek to enhance their performance by reducing the supply of modules or components below the competitive level thereby increasing prices above the competitive level. In other words, these suppliers focus primarily on revenues to enhance performance. On the other hand, strategic alliances are formed to enhance the performance by exploiting synergies. These synergies in turn can reduce costs of the cooperating suppliers, increase revenues, or do both. It should be noted that organisations often have strong economic incentives to cheat on cooperative agreements in tacit collusion. Moreover, because explicit collusion is typically illegal, the ability to collude depends on specific industry characteristics (e.g. small number of competing organisations, homogeneous cost, and homogeneous products) together with highly developed skills to interpret signals that may indicate the willingness to collude. Kogut (1988) concludes that, although tacit collusion is not impossible, strategic alliances are more common.

In general, suppliers have an incentive to cooperate in strategic alliances, either with other suppliers or OEMs, when the value of their resources and assets combined is greater than the value of these separately. One of the most often cited reasons for the development of strategic alliances in the mature automotive industry is the sharing of costs and risk reduction. Often, investments required to exploit an opportunity (e.g. development of composite materials and engine technology) can be very high. Forming strategic alliance spreads the risk of failure by sharing the costs among organisations. Furthermore, these alliances are also often used to learn important skills and abilities from competitors (Wildemann, 1996). The otherwise competing organisations may have an incentive to cooperate even though cooperation may help an organisation compete in all of its business activities, not just the strategic alliance.

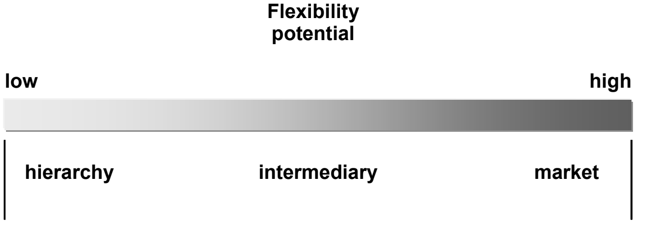
2.6 Modular sourcing and vertical integration

2.6.1 The cost of governance

This paragraph examines the conditions under which organisations can leverage their traditional resources to gain competitive advantage and economic profits. When modular sourcing is applied the extent of business activities across the different stages of the value chain is reduced for the OEM. The number of stages in a product's value chain[14] in which the OEM decides to engage, defines the level of vertical integration.

Vertical integration decisions can be understood as a particular example of governance choices that organisations make in order to organise their economic activities. In other words, vertical integration is a valuable form of governance when its benefits outweigh its costs. Even though vertical integration is an important way in which organisations can organise their exchanges, it is only one of a wide variety of governance choices available to managers. The broad range of possible governance mechanisms and their flexibility potential is represented in figure 2-9.

Figure 2-9: Range of governance mechanisms



On the right hand side of the spectrum, parties to an exchange may interact across a faceless and nameless market and rely entirely on market-determined prices to manage an exchange. On the left-hand side, the other extreme is depicted that manages exchanges within a single entity. Supply chain parties can use different intermediary coordination forms as well (e.g. spot market contracts, complete contingent claim contracts, sequential contracts, relational contracts, internal markets, bureaucracy, and clan governance) to manage an exchange. If a particular exchange can be regarded as potentially valuable, the purpose of the governance structures is to minimise the threat that exchange partners will be unfairly exploiting each other in an exchange and to do so at the lowest cost possible (Coase, 1937; Williamson, 1985; Hosenfeld, 1993). Exploiting the vulnerabilities of the exchange partner is also referred to as 'opportunism' (Williamson, 1975). Exchange partners need to concern themselves with both minimising the threat of opportunism and minimising the cost of managing it (Barney, 2001).

[14] A value chain refers to a set of vertically related activities (see Porter, 1985).

Wolters (1995) and Brand (1990) studied the diversity of transaction costs among the vastness of publications and concluded that search, information, bargaining, control and adaptation costs are the most widely accepted among researchers. Williamson (1975) distinguishes several cost drivers (environmental factors, human factors and transaction conditions) that determine the height of transaction costs thus influencing the governance (see Appendix B).

The transaction cost logic has been subjected to a great deal of empirical research in economics, organisational theories and strategic management. Much of this empirical research supports essential elements of the transaction cost theory. Studies on the environmental and human factors found -to some extent- coherence between these factors and the level of vertical integration. After a study of 91 suppliers, Lyons (1994) concluded that formally written contracts are positively related to the risk of opportunistic behaviour. Other researchers (e.g. Kogut, 1991; Balakrishnan & Koza, 1993) have provided evidence that under uncertain and complex conditions exchange partners choose more market-oriented contracts. Furthermore, Barney (2001) concludes that hierarchical governances are usually less flexible than intermediate or market forms. Other researchers (e.g. Baur, 1990; Noordewier *et al.*, 1990) suggest that under uncertain and complex conditions, a hierarchy is preferred in order to reduce opportunism. However, the discussion among researchers on the determinants of the transaction costs has not generated strong conclusive findings and is continuing.

On the other hand, empirical research on the impact of the transaction conditions (especially the transaction specificity) has provided much stronger findings. Several empirical studies (e.g. MacMillan *et al.*, 1986; Caves & Bradburd, 1988) provide evidence that organisations that need to make transaction-specific investments are more likely to be vertically integrated than organisations that do not require this type of investment. Furthermore, MacDonald (1985) concluded that the greater the level of the site specificity of an investment, the more likely that this relationship is managed through a hierarchical governance. Finally, some studies (e.g. Armour & Teece, 1980; Masten *et al.*, 1991) have examined the role of transaction specific human capital investments on vertical integration decisions and similarly concluded that specific investments are likely to be co-ordinated in a hierarchy.

Decisions to apply modular sourcing have often not been considered under the explicit consideration of costs and benefits. However, in their zeal for outsourcing, some organisations have gone too far and outsourced too many activities. Outsourcing the exchanges that are most likely to generate competitive advantages for an OEM puts those competitive advantages at risk.

2.6.2 Capabilities and governance

The transaction cost logic assumes that the value of an economic exchange is given, and that the task facing managers is simply to choose the form of governance that minimises the threat of opportunism in extracting this value at the lowest cost possible (Williamson, 1991). However, the transaction cost logic does not recognise that the way in which an exchange is governed can have a direct impact on the value an exchange can create. In other words, the governance itself can be a source of economic rents, which is supported by the 'resource-based view of the firm' (Penrose, 1959; Learned *et al.*, 1969; Barney, 1991). This theory contradicts some critical points of the transaction cost theory and argues that specific organisational resources achieve superior organisational performance.

Two propositions about the extent of vertical integration can be derived from the resource-based view according to Barney (2001). First, non-hierarchical governance structures should be chosen in spite of the threat of opportunism[15]. Second, organisations should vertically integrate the activities with which it can achieve a competitive advantage[16]. The underlying assumption of these propositions is that different organisations may have different kinds of resources and capabilities ('resource heterogeneity'). In addition to making governance choices that minimise the threat of opportunism, the organisation has to consider the potential value created by being able to work with other unusually skilled organisations (Barney, 2001). In contrast to the transaction cost theory, the threat of opportunism does not only determine the choice of governance. Rather, these costs should be balanced against any value that is created by the interaction with other organisations. When the value created is higher than the cost of opportunism, less hierarchical governance structures should be chosen.

The consideration of capabilities only becomes important when they are potentially valuable, rare, costly to imitate[17], and too costly to be acquired (Barney, 1999). An organisation that possesses valuable capabilities and resources is likely to be acquired. However, the cost of acquisition in these situations may be greater than the value of such an acquisition, which is often reflected in the marketplace by lower stock prices after completing the acquisition. Sometimes organisational capabilities and resources are valuable exactly because they are not owned by another organisation (Kanter, 1993). Such resources and capabilities are highly organisational specific, which means that they exist in a particular setting at a

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[15] This proposition contradicts the transaction cost theory.

[16] This proposition corresponds to the transaction cost theory.

[17] This may reflect the organisations unique history or may be socially complex.

specific time because of the organisational history. This implies that in some cases, a decision to vertically integrate in the hope of gaining access to specific resources would not generate enough economic value. In addition, governmental law and regulations of certain countries can prevent the acquisition of organisations (Barney, 2001). The acquisition of an organisation in order to reduce the extent of opportunism is made impossible by governments. In particular globalising organisations that try to enter new marketplaces often depend on some type of interaction with a domestic organisation. However, the risk of opportunism is high in these situations especially if transaction specific investments have to be made, which would favour a vertical integration. When government regulations do not allow this, the organisation has to decide if the potential costs associated with any opportunism that might emerge are lower than the economic value created by the interaction (Dyer & Ouchi, 1993)[18].

As described above, organisations should vertically integrate the activities with which they can achieve a competitive advantage. Argyris (1996) describes two reasons why organisations should vertically integrate business functions in which they currently enjoy competitive advantages. First of all, hierarchical governances can increase the possibility that the organisation will keep the sources of its competitive advantage in comparison to non-hierarchical governances. If an OEM uses suppliers to acquire a potential competitive advantage, the OEM will generally have to contact several possible suppliers before selecting one. This increases the chance that the source of an organisational competitive advantage will become known to other OEMs, which in turn reduces the chances that it eventually will become a competitive advantage. Second, the organisation that vertically integrates another will be able to appropriate the economic rents that the source of competitive advantage is likely to generate (Coves, 2000). If an external partner generates these rents, those sources have the ability to extract some of the profits themselves for the actions they create. When this external partner is integrated, the acquiring organisation can appropriate a larger portion of the economic rent that is generated.

Observing these arguments, it can be stated that when a set of business functions is likely to be a source of competitive advantage, organisations will have to manage this (when possible) through more hierarchical governances. If, on the other hand, business functions are not likely to be a source of competitive advantage then it is possible to manage this in non-hierarchical governance structure, which is consistent with the transaction cost theory.

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[18] European and U.S. organisations are often confronted with this situation in the Chinese and Japanese market place.

2.6.3 Governance choices

In the previous paragraphs, insights from both the 'transaction cost theory' and 'resource-based view of the firm' have been used to discuss governance considerations. In this paragraph, these somewhat contradicting theories are integrated to gain a more balanced view on governance choices.

Departing from the fundamentals of the neoclassical economics, Ronald Coase (1937) questioned the notion of frictionless markets in his article 'The nature of the firm'. The main purpose of his publication was to explain why economic activities are organised within organisations. Based on this Williamson (1975, 1985) made the transaction cost theory more predictive by approaching the organisation as a governance structure and by identifying transaction cost characteristics. In spite of the difference in focus of the two authors, both observe organisations as an alternate means of coordination. Organisations are supposed to be coordinated through authority and market by price mechanisms.

The transaction costs theory has been criticised many times by authors such as Teece (1990), Teece & Pisano (1994), Meyer (1994), and Wolters (1995). This criticism is primarily aimed at quantifying the transaction costs. However, Williamson (1985) argues that the objective is not to quantify the costs of the different coordination forms in absolute terms:

> *"…accordingly, it is the difference between, rather than the absolute magnitude of the transaction costs that matters… (Williamson, 1985, p. 22)"*

Williamson (1985) argues that the difference between the total costs of external sourcing with the relevant production costs in the case of internal sourcing are the transaction related costs. However, Wolters (1995) criticised this procedure and argues that opportunity costs should be observed as well. Furthermore, Wolters (1995) argues that internal costs can only be subjectively established.

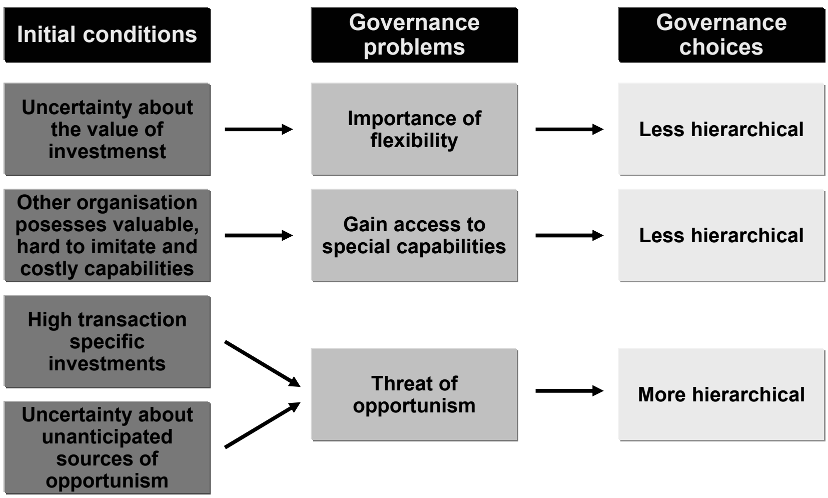
Probably most criticism on the transaction cost theory comes from the 'resource-based view of the firm'. The latter mentioned view argues that the reason an activity is conducted within an organisation is, not due to market failure, but rather organisational success in the form of capabilities (Madhok, 2002). The organisation is an institution with different kinds of resources and capabilities, which enable it to organise economic activity in a manner that markets simply cannot (Barney, 2001). In addition, Teece, (1990) not only addresses efficient contracts and governance structure, but also production and organisational economics. The 'distinctive ways' as described by Teece (1990) in which organisations manage their resources and capabilities can result in superior performance and function as an enduring source of competitive advantage (Barney, 1991).

Madhok (2002) argues that the transaction cost theory and resource-based view are highly interrelated and that many valid arguments are available for both approaches. The transaction cost theory anticipated many of the critical issues in the resource-based view including the central question of performance differences among organisations. Madhok (2002) points out that the division of labour between the organisation and the market is actually a division of labour between organisations, and therefore has to do with the distribution of economic activity between organisations. Exactly this issue, framed in terms of performance differences across organisations, is the fundamental focus of the resource-based view. The resource-based view cautions organisations against outsourcing too many activities since organisational routines are a building block for capabilities. These routines are used to explain various phenomena such as path dependence, organisational inertia, learning, and knowledge stocks (Dosi *et al.*, 1992). Each organisation has a basic source of competence that is gradually accumulated through experience and routines, which becomes the source of competitive advantage and at the same time a constraint (Madhok, 2002). According to the resource-based view, the source of an organisational competitive advantage lies in those activities that an organisation is able to conduct in a superior manner as compared to others. Such differences would explain why an activity is organised within a particular organisation and not by the market (Langlois, 1992). Moreover, such an advantage is the logical outcome of a superior cost position and therefore, the emphasis of Coase (1937) on the lowest transaction cost is equivalent to the argumentation of the resource-based view (Madhok, 2002). The resource-based view considers cost as a 'tool' in achieving a competitive advantage. Given the quasi-paradigmatic differences and the fact that the two theories have different focuses, it is not surprising that the respective approaches in understanding organisational behaviour and economic organisation differ.

Despite the argumentation of Madhok (2002) regarding the similarities between the resource-based view and transaction cost theory, the focus of the two approaches remains fundamentally different. The competitive advantage is the focus of the resource-based view, whereas the governance structure is the domain of interest of the transaction cost theory.

Adler (1993) provided empirical evidence that the interdependence between production and exchanges not only occurs in the area of costs, but also in terms of knowledge and learning. Other authors (e.g. Teece, 1990, Ghoshal & Moran, 1996) argue that organisations are not just efficient governance structures, but also institutions for learning. In order to understand both governance and sources of competitive advantage the transaction cost theory, resource-based theory as well as the knowledge-based theory should be integrated to get a more comprehensive view of coordination mechanisms (Lorenzoni & Lipparini, 1999). Dyer & Singh (1998) and Adler *et al.* (1999) conclude that the choice of specific governance structure can result in performance differences; this underlines the importance of integrating multiple theories in explaining governance choices. Barney (2001) developed a model that integrates the relative importance of the transaction cost theory, resource-based view and real options theory, and is adopted in this study (see figure 2-10).

Figure 2-10: Weighted model for governance decisions



In this model the relative importance of theories is observed. Depending on the initial conditions that define governance problems an appropriate choice is offered. Next to the inclusion of the transaction cost theory and resource-based view of the firm, the real option theory (e.g. Amram & Kulatilaka, 1998; Copeland & Antikarov, 2001) is added as well. Barney (2001) argues that the latter mentioned theory is necessary to observe since previous studies on the relationship between environmental factors and governance choice have not delivered strong conclusive findings.

The real option theory argues that organisations are able to adjust their strategy in the future depending on how that uncertain future evolves[19]. Given the importance of the ability to adjust the strategy over time, the real option analysis of

[19] The use of options allows organisations to exercise the right (not obligatory) to buy or sell a specified asset at a pre-specified price on a pre-specified point in time.

governance suggests that when there is significant uncertainty about whether or nor a specific investment will ultimately be valuable, choosing the governance that maximises the strategic flexibility becomes prime (Kogut, 1991).

Observing the initial conditions in figure 2-10, it can be concluded that if the uncertainty about the value of future investments in specific assets is high, the value of flexibility in the transaction is high and therefore the real option theory should dominate governance decision-making. As a result, less hierarchical governance structures are preferable. In situations in which the value of gaining access to another organisation's rare, valuable, costly to imitate and costly to acquire resources and capabilities is high, then the resource-based view should dominate governance considerations and less hierarchical governance structures should be chosen (despite the threat of opportunism). Finally, if the importance of counteracting the threat of opportunism is relatively high, then the transaction cost logic should dominate and more hierarchical governance structures are preferable. It should be noted that the model of Barney (2001) assumes that the economic value of a particular transaction is given. Yet, it does not observe the role of the structure itself in creating value for the transaction. In other words, the governance itself can be a source of economic rents as well.

Observing this discussion, it becomes apparent that multiple theories should be integrated in order to explain governance choices. For example, researchers have also made efforts to integrate theories such as the knowledge-based theory (Lorenzoni & Lipparini, 1999), the principal agent theory[20] and the game theory[21] (Wolters, 1995). The discussion among different research approaches is increasing which is an important development for gaining a better understanding of coordination structures. Even Williamson (1999) acknowledges the importance of organisational specifics in his latest study. The effort to design more integrative models is continuing in order to better understand the governance choices that can be applied.

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[20] The principal agent theory focuses on the differences in goals between the principal (OEM) and the agent (module supplier) (see Jensen & Meckling, 1976).

[21] The game theory shows the underlying logical structures of strategic conflicts between parties and tries to visualise solutions (see Rapoport, 1966).

2.7 Conclusions

In this chapter, the elements of the ‘environment-strategy-structure-performance’ paradigm (Lawrence & Lorsch, 1967) have been analysed. Furthermore, the types of fit described in the model are used to explain why modular sourcing has increasingly become important in the automotive industry. In an overview of changes in management thinking, classical and modern management theories were discussed as well as the rationalisation process of manufacturing operations. Furthermore, it is questioned whether lean production is in all cases superior to mass production processes. The environmental turbulence that organisations in the automotive industry face has been analysed by observing unpredictability, complexity and dynamism. These aspects largely influence the ‘fit’ between the environment and the chosen business strategy. Since the number of vehicle offering has grown over the years, the complexity of the product program has increased as well. In addition, the ‘complexity trap’ model explained the difficulty of grasping the effects of increased complexity on costs. Next, the economic value of differentiation strategies was examined followed by the analysis of global strategies. Both strategies can be simultaneously applied and can be considered as complementary. Based on the analysis of key scientific contributions, modular sourcing has been defined for this study. Furthermore, the principles of modular sourcing have been explained and a supplier classification has been described as a basis for further analysis. Finally, both the extent of vertical integration and the appropriate governance choices have been discussed using insights from the transaction cost theory, resource-based view of the firm, and real option theory. In order to get a more comprehensive view on governance choices a model was adopted in which the relative importance of these theories was observed.

3 Manufacturing flexibility

Unfortunately, beyond confusing the concept of flexibility, current studies do not suggest an explicit analytical framework for the understanding of flexibility. The need to explicitly consider flexibility makes it necessary to clarify it and to define measures for each classification.

(Bernardo & Mohamed, 1992, p. 145)

3.1 Research on manufacturing flexibility

In this chapter manufacturing flexibility is analysed as a basis for the development of the conceptual framework in chapter 4. In this paragraph, the existing research on manufacturing flexibility is examined followed by a brief discussion of strategic flexibility in paragraph 3.2. Paragraph 3.3 discusses several criteria that can be used to structure flexibility dimensions. The definition of manufacturing flexibility dimensions is the subject of paragraph 3.4. Based on these definitions a hierarchy of flexibility dimensions is developed in paragraph 3.5. Finally, paragraph 3.6 summarises the most important conclusions of this chapter.

In the available literature many manufacturing flexibility definitions and dimensions are offered. However, these dimensions are often confusing and have a tendency to only focus on the internal organisation. Furthermore, the theoretical basis of the developed flexibility models is limited which makes the domain specifications questionable (Churchill, 1979; Venkatraman & Grant, 1986). Before more comprehensively defining the domain of manufacturing flexibility that observes both internal and external factors, several key publications are analysed.

Much of the manufacturing flexibility research from the 1970's and 1980's focussed on the drivers of flexibility and thus provided a basis for the initial understanding of this concept. Since then, numerous studies have appeared that focus on aspects such as: the economic advantages (e.g. Hutchinson, 1989), the effects on decision-making (e.g. Mandelbaum, 1990), and the quantification of performance indices (e.g. Brill & Mandelbaum, 1989). Moreover, the multi-dimensional concept of manufacturing flexibility has been influenced by management practices and operating policies. As such, there are different viewpoints from which manufacturing flexibility can be observed.

Manufacturing flexibility can be regarded as having either a reactive or a proactive nature (Gerwin, 1993). The reactive nature of flexibility addresses the environmental turbulence faced by organisations (Slack, 1983). The proactive use of flexibility enables organisations to redefine market uncertainties and influence customer behaviour. Also, the extent of manufacturing flexibility can be regarded as either actual or potential (Koste, 1999). Actual flexibility reflects the current extent of manufacturing flexibility that a specific resource or organisation achieves. On the other hand, potential flexibility reflects the hypothetical nature of flexibility. As described in paragraph 1.5, only the actual flexibility is observed and is compared to an alternative option to assess the magnitude. For this reason, the extent of manufacturing flexibility is observed as a relative attribute as opposed to an absolute one (Tidd, 1991). Table 3-1 provides a summary of the key elements of these publications.

Table 3-1: Overview of key manufacturing flexibility literature

	GUPTA & SOMERS (1992)	**DIXON (1992)**	**HUYN & AHN (1992)**	**KOSTE (1999)**
Flexibility dimensions included	9 dimensions: volume, process programming, product & production, market, machine, routing, material handling, and expansion & market.	3 dimensions: mix, new-product, and modification.	9 dimensions: machine, routing, control, worker, expansion, product, mix, volume, and program.	10 dimensions: modification, new product, mix, volume, expansion, routing, operation, material handling, labour, and machine.
Hierarchy	1 level	1 level	3 levels	5 levels
Scale items	34 initially; 21 in final instrument	39 initially; 22 in final instrument	No items	140 initially; 24 in final instrument
Research design & statistical analysis	Survey (n = 269) Factor analysis	Survey (n = 29) Diverse statistical methods	Conceptual No statistics applied	Survey (n = 158) Factor analysis
Major strength	Measures taken from broad range of existing literature.	Sophisticated items for product related dimension.	Conceptualisation of manufacturing flexibility hierarchy.	Extensive study of scale items.
Major weakness	No hierarchy development despite supportive relationships.	Limited domain specification caused by limited number of dimensions. Questionable validity caused by small number of responses.	Lack of validation.	The hierarchical levels proposed create interpretation problems. Weak reliability and convergence validity of certain flexibility dimensions.

Among all key publications, manufacturing flexibility is recognised as a multi-dimensional concept. In these publications, many different flexibility dimensions are distinguished, yet they are not clearly specified resulting in overlapping and confusing definitions. In addition, the differences in flexibility definitions reflect the variety of flexibility hierarchies among these publications (see paragraph 3.5).

Among the key publications, different flexibility dimensions can be distinguished. Gupta & Somers (1992) define nine dimensions and a corresponding hierarchy largely based on the work of Sethi & Sethi (1990) who in turn distinguish eleven dimensions. After their empirical research Gupta & Somers (1992) concluded that the nine dimensions (volume, programming, process, product & production, market, machine, routing, material handling, and expansion & market) of manufacturing flexibility explained 72% of the total variance, which was concluded sufficient. On the other hand, Dixon (1992) distinguishes three product-related dimensions (mix, new product, and modification) that are considered to have a highest competitive potential. Hyun & Ahn (1992) distinguish nine dimensions (machine, routing, control, worker, expansion, product, mix, volume, and program) of manufacturing flexibility. Even though these dimensions are only briefly explained, they build a broader basis for the domain specification of manufacturing flexibility. Finally, Koste (1999) distinguishes ten dimensions (modification, new product, mix, volume, expansion, routing, operation, material handling, labour, and machine) of manufacturing flexibility. The extensive discussion of these dimensions is comparatively the most comprehensive, yet lacks the inclusion of machine layout factors.

Among the key publications different hierarchies were developed. Hyun & Ahn (1992) and Koste (1999) observe multiple layers in their flexibility hierarchy, in which the lower level flexibility dimensions form building blocks for higher levels. These hierarchies will be discussed in paragraph 3.5.

Despite the contributions of these key publications, as well as others, there is a lack of good general applicable items and measures. (De Toni & Tonchia, 1998). The study of Gupta & Somers (1992) initially distinguished 34 scale items. After purification and reliability assessment 21 items were retained. Dixon (1992) initially developed 39 items from which 22 were maintained in the final instrument. Even though these product-related scale items showed a good reliability, they were only applicable in the textile industry. The publication of Hyun & Ahn (1992) has a conceptual character; consequently no scale items were developed. Finally, Koste (1999) initially developed 140 items from which 24 were retained in the final instrument that had a just about level of reliability.

Among the key publications, different research designs were applied. Gupta & Somers (1992) used a survey of 269 organisations and applied factor analysis to validate the measures. In order to determine the convergent and discriminant validity, additional data from 113 organisations was collected. Dixon (1992) used a survey as well and initially applied factor analysis. Since only 29 surveys were used, it was decided to that the validation of measures for single variables associated with the dimensions had to be met in a different manner. As a result, the principal factoring method was used to validate the correlation matrices, which in turn was the basis for selecting the sum score components. Despite this effort to approach the level of accuracy in commonly applied factor analysis, it remains an insufficient, and therefore, weak approach. Koste (1999) used the survey results of 158 respondents and applied both exploratory and confirmatory factor analysis to establish and validate the measurement properties.

3.2 Strategic flexibility

Ansoff (1965) was one of the first authors who explored the concept of flexibility in his book "Corporate Strategy". From a contingency perspective, he suggested that external organisational flexibility can be achieved through a product-market mix, which is sufficiently diversified to minimise the negative effect from disturbances that can arise. Eppink (1978) stated that Ansoff's (1965) approach to flexibility has a passive context since it is defined in terms of limiting the impact of the environmental turbulence on organisations. Eppink's (1978) own definition includes both an active and passive component:

> *"Flexibility can be seen as a characteristic of an organisation that makes it less vulnerable to unforeseen external changes or puts it in a better position to respond successfully to such a change (Eppink, 1978, p. 42)."*

Eppink (1978) explicitly related flexibility to unforeseen change whereas for the ability to respond to foreseen change the term 'adaptiveness' is used. In other words, the total responsiveness would then consist of adaptability and flexibility. Even though Eppink (1978) suggested that there may be some overlapping between these two aspects, he does not further explain this point.

By contrast, scholars such as Ackoff (1971) and Reichwald & Behrbohm (1983) relate passive flexibility to the acceptance that the environment cannot be changed and that organisations need to adapt. Furthermore, active flexibility refers to trying to change the environment itself. Because of these differences among researchers, Volberda (1999) suggests the use of the term 'external flexibility' for Eppink's passive notation and the term 'internal flexibility' for the active notation. Internal flexibility goes together with self-adaptation, while external flexibility requires others to adapt.

Aaker & Mascarenhas (1984) consider organisational flexibility as a strategic option that can be exercised by an organisation. These authors argued that when organisational changes become increasingly undefined, fast moving, and numerous, it is risky to rely upon conventional strategic management approaches. Another approach is to exercise the strategic option of developing organisational flexibility that is defined as:

> *"… the ability of the organisation to adapt to substantial, uncertain, and fast-occurring environmental changes that have a meaningful impact on the organisation's performance… (Aaker & Mascarenhas, 1984, p. 74)."*

Their emphasis is on substantial environmental turbulence, which imposes severe long-term constraints and creates a need for strategic adaptation. In considering this strategic option, Aaker & Mascarenhas (1984) suggested that flexibility could be achieved by diversification strategies, investments in underused assets, and reducing specialised commitments (e.g. reducing specialised facilities). When considering strategic flexibility, an organisation should consider whether it is necessary to increase its flexibility and, if so, which approach is the most appropriate and effective. According to Aaker & Mascarenhas (1984), this flexibility decision involves a series of steps. First of all, the external changes have to be identified, evaluated, and finally the flexible option should be considered. Moreover, strategic flexibility is increasingly becoming a necessity instead of a choice and is often used to denote the organisation's deliberate or emerging capabilities to manoeuvre defensively or offensively (Evans, 1991) in dynamic competitive environments (Boynton & Victor, 1991).

Observing the literature, strategic flexibility can be regarded as a way to achieve some form of control in turbulent environments. While bureaucratic forms based on hierarchy and commitments provide a certain form of static control in stable environments, highly turbulent environments require flexible modes to achieve dynamic control (Volberda, 1999). This need implies that a flexible organisation must deal with threats and opportunities, which can have important consequences for its functioning. Organisations have to continuously observe and translate these aspects with respect to their degree of intensity, and try to influence them in a positive manner.

Among the flexibility publications, not only do the capability to respond need to be considered, but also the required reaction time. The reaction time refers to the speed with which an organisation can run through the various control cycles (Aaker & Mascarenhas, 1984; D'Aveni, 1994). Furthermore, the reaction time can be divided into retardation and warning time (Reichwald & Behrbohm, 1983). Retardation time refers to the time period between the actual change (shift in activities) and the moment when adequate action is taken. The warning time covers the time elapsed between the moment when a possible change is signalled and the moment the change actually happens. It should be noted that in situations of abrupt changes, there is no warning time. For this reason, Ansoff *et al.* (1975) argued that in confronting a discontinuity, management may act decisively, which refers to an immediate reaction. Furthermore, management may wait until the impact has reached a certain threshold level before action is taken.

3.3 Structuring manufacturing flexibility dimensions

3.3.1 Range

In describing manufacturing flexibility dimensions several researchers (Slack, 1987; Upton, 1994; Koste, 1999) recommend using the elements of range (R), mobility (M), and uniformity (U). These elements will be briefly described and are included in the definitions of the flexibility dimensions to more comprehensively capture their domain.

The 'range' element can be used to structure manufacturing flexibility dimensions, which is well supported by researchers (Slack, 1987; Upton, 1994; Koste, 1999). Even though Slack (1987) and Upton (1994) both recommend using the range element, the terminology they use is different. Slack (1987) defines range as:

> *"… the number of possible states in which a particular system can operate…(Slack, 1987, p. 37)".*

If a system can operate in a wider range it is considered more flexible than a corresponding system with a smaller range. In other words, this range refers to a strict numerical count of the number of possible options that a system or a resource can achieve (e.g. number of operations a machine can perform). Upton (1994) using a broader definition than Slack (1987) defines range as:

> *"… the number of viable positions within the range or some metrics of the distance between extremes of the range... (Upton, 1994, p. 80)."*

This first part of the definition is congruent with the definition of Slack (1987), whereas the latter addresses the heterogeneity of the options. The heterogeneity describes the degree of difference between these options and is determined by the different products produced using the same assembly line. In other words, the products produced using the same assembly line may be quite similar of differ largely from each other. This addition is an important one, since not only the different states of the manufacturing system are observed, but also the differences among the products produced.

To illustrate the importance of the number as well as the heterogeneity of options, consider plants A and B. Plant A produces two different convertible models, while plant B produces a limousine and a sports utility vehicle (SUV). Both models in plant A use the same technology platform, while the limousine and SUV produced in plant B have different technology platforms and associated assembly lines. Thus, in comparison to plant A, plant B will encounter different processing and material requirements for the assembly of both a limousine and SUV. If just the number of products were considered, plants A and B would be ranked as having the same range. However, if product heterogeneity were taken into account, plant B would be deemed as more flexible. Therefore, both the number of options and the heterogeneity need to be observed in the definition of manufacturing flexibility dimensions.

3.3.2 Mobility

In describing manufacturing flexibility dimensions the use of 'mobility' (M) aspects is equally supported by researchers (Slack, 1987; Upton, 1994; Koste, 1999). Upton (1994) defines the mobility of a manufacturing system as:

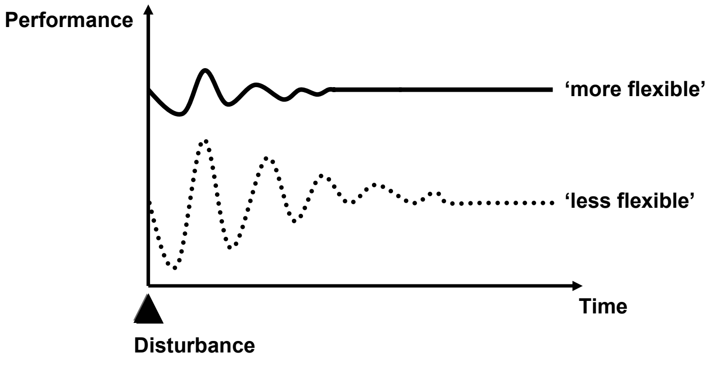
> *"…the ease with which an organisation moves from one state to another (Upton, 1994, p. 83)."*

This definition is similar to the 'ease of movement' as proposed by Slack (1987). In order to assess mobility, both Slack (1987) and Upton (1994) suggest that the objective measures, time and costs, are to be used because of their interrelatedness. In addition, Gupta & Buzacott (1989) suggest that the speed of the transition also needs to be considered in valuing mobility. In order to assess this, Upton (1994) suggests the observation of so-called 'transition penalties'. These penalties are solely related to the movement within the range and not to the costs to acquire or develop the range of flexibility. Transition penalties assess the difficulties (e.g. lost production time, scheduling efforts) of implementing a different flexible alternative that is necessary in a flexible response (Upton, 1994). Therefore, an organisation that incurs smaller transition penalties for similar gains in the number and heterogeneity of options is considered more flexible (Koste, 1999). In general, the mobility of a manufacturing system is increased when the sum of the transition penalties is lower than it was before the measure was implemented.

3.3.3 Uniformity

The inclusion of 'uniformity' (U) in defining flexibility dimensions has been recognised by Gupta & Buzacott (1989), Upton (1994), and Koste (1999), but has been omitted by Slack (1987). Uniformity refers to the similarity of performance outcomes of a manufacturing system after a particular disturbance (see figure 3-1).

Figure 3-1: Principle of uniformity



A more flexible system will show less peaks and valleys in performance outcomes than a less flexible system. Furthermore, the height and peaks are lower in a more flexible manufacturing system. In contrast to transition penalties, the peaks and valleys are not incurred once but could affect flexibility for a sustained period of time or even for the entire duration of the flexible response (Upton, 1994). In other words, the uniformity represents the consequences of a disturbance over time in terms of performance outcomes.

In order to assess the level of uniformity performance indicators such as quality, efficiency, effectiveness and costs can be used (Johnson & Kaplan, 1987; Upton, 1994). The net sum of changes in these performance outcomes indicates the level of uniformity. In the best possible situation a manufacturing system's flexible reaction would, theoretically, not influence performance at all (neither positively nor negatively). It should be noted that trade-offs between these performance variables may exist. Therefore, caution should be taken when interpreting the level of uniformity.

3.4 Dimensions of manufacturing flexibility

3.4.1 Process flexibility

The contingency theory is based on the assumption that organisations react in predictable ways to conditions surrounding them and adjust their purpose and shape to meet environmental characteristics (Miles & Snow, 1978). Furthermore, environmental conditions are regarded as a direct source of variation and the primary aim of an organisation is to achieve the best possible ‘fit’ (see paragraph 2.1). The underlying principles of the contingency approach have become established as a dominant perspective in organisational analysis, in which environmental factors are viewed as an important influence on the behaviour of organisations (Volberda, 1999).

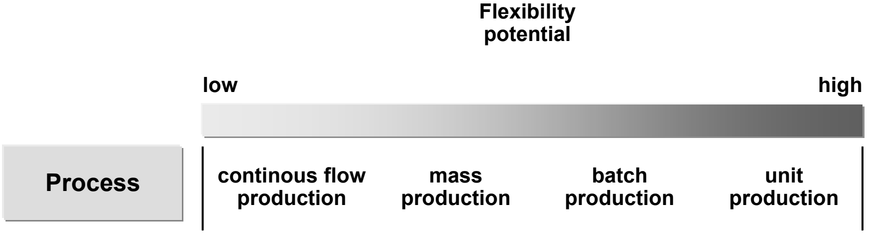
Burns & Stalker (1961) stated that when changes in the environment become prevalent, open and more flexible organisational processes are required. Moreover, Woodward (1965) discerned the relationship between technology and the structure of successful organisations. Woodward (1965) concluded that the principles of the classical management theories are not always the right ones to follow, since different technologies impose different demands on organisations that have to be met using the appropriate process choices. Hence, based on the insights of the contingency theory, Woodward (1965) developed a technology-based scale for these process choices which is a threefold classification of technology with several sub-groups. Technical complexity was conceptualised as a range including a single unit production process (high complexity), an intermediate form, and a continuous flow process (low complexity).

This continuum was criticised extensively over the years and has been revised several times. The most important critics (e.g. Starbuck, 1965; Hunt, 1970) have added process choices in order to smoothen the steps from one process to the next. The continuum in figure 3-2 is based on a compilation of Woordward (1965), Starbuck (1965) and Volberda (1999)[22]. In this continuum, continuous flow production represents a highly regulated process that comes close to what Mintzberg (1979) calls ‘complete automation’. In general can be stated that the more regulating the mode of production, the less flexibility potential is achieved. Observing the left side of the continuum, the flexibility potential is inhibited by technological constraints. Continuous flow and mass production is typically restricted by many regulations with impersonal control of the process. Typical for

[22] It should be noted that this continuum is based on the relative size of output and does not value the ‘leanness’ of processes.

the mass production system is the fact that all products pass through the same sequence of operations.

Figure 3-2: Process flexibility potential



On the right hand of the continuum, batch and unit production have the least regulating mechanisms. Batch processes refer to a mode of operation in which each production-lot passes through one stage of the process before entering the next (van Donk *et al.*, 1991). This means that the production capacity at each stage of production is used to meet the different requirements of orders. Unit production refers to the assembly of vehicles without the use of an assembly line and is often used for low volume vehicle models. In mass production and batch production, process times will tend to be short and plant utilisation high. Even though the performance of the mass production system on output (measured as throughput time and volume output) is higher, the extent of freedom to react to sudden changes in demand is lower than in batch processes.

Process flexibility has been frequently studied and appears in both conceptual (e.g. Chen *et al.*, 1992) and empirical research (e.g. Gupta & Somers, 1992; Koste, 1999). This dimension includes aspects such as process routing[23], material handling[24], and sequencing. In some studies (e.g. Gupta & Somers,

[23] Routing is often defined in terms of the ability to use alternate routes through the system in order to produce a vehicle. Routing has a potential character when routes are predetermined in case of a malfunction. The actual character of this element focuses on dynamics of the routing capability during a breakdown (see Gupta & Somers, 1992).

[24] Material handling is another important aspect of process flexibility and refers to the loading and unloading of parts under various conditions (Chen *et al.*, 1992; Gupta & Somers, 1996).

1992; Koste, 1999) these aspects are considered as separate dimensions at different hierarchical levels (see paragraph 3.5).

The level of process flexibility should be assessed within the current manufacturing system but without set-ups or facility modifications (Sethi & Sehti, 1991; Gupta & Somers, 1996). These constraints are necessary since the measurement of the level of flexibility would otherwise be confounded by short-term capital-intensive measures to increase flexibility. The number of alternate processing plans and the heterogeneity of the processing sequence captures the range of process flexibility. The time and costs incurred to switch from one processing plan to an alternate one make up the transition penalties which indicate the level of mobility. Finally, quality levels, product costs and output level are performance outcomes that could be monitored in order to derive the level of uniformity of a particular manufacturing system. In accordance with the description above, the following definition of process flexibility is proposed:

The number of products that have alternate processing plans and the variety (heterogeneity) of processing operations used without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

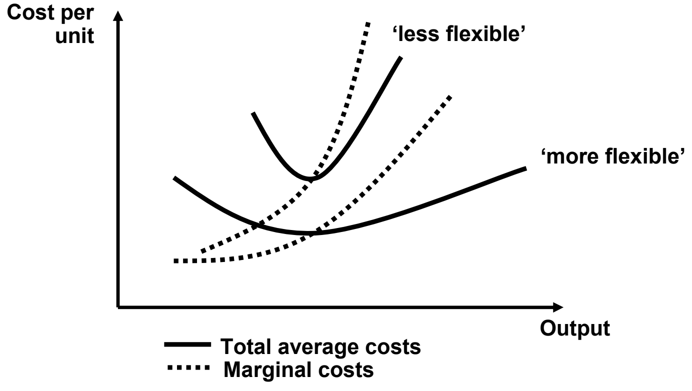
3.4.2 Volume & expansion flexibility

Volume flexibility relates to the ability to increase the volume produced by the manufacturing system in order to quickly respond to market changes and still be profitable (Hyun & Ahn, 1992). This implies that the manufacturing system is productive even at low levels of utilisation. The principle behind volume flexibility is depicted in the figure 3-3.

If the average total cost curve is U-shaped and is very ‘flat’, the marginal cost curve rises more slowly. Slow rising marginal cost curves in turn indicate a higher level of flexibility (Carllson, 1989). The ability to accelerate production very quickly, without dramatically raising costs, is constrained by the available production capacity and existing technology. A production network has a positive effect on the volume flexibility when the production of multiple products can be shifted within this network.

The aggregate output achieved by a particular manufacturing system indicates the range-number. Krajewski & Ritzman (1996) suggest that the effective capacity of the manufacturing system that is economically feasible under normal conditions should be observed instead of the design under maximal occupation. The changes in the aggregate volume that can be added to a few products only, or an entire product-line, indicate the level of range-heterogeneity. Eidenmüller (1989) refers to the heterogeneity as the ability to produce small lots and leads for a given product mix. The time and costs required to change the level of output is a possible transition penalty and indicates the level of mobility. Performance outcomes include efficiency and quality levels that should be observed to determine the level of uniformity.

Figure 3-3: Volume flexibility based on cost curves



In accordance with the description above, the following definition of volume flexibility is proposed:

> ***The ability of a manufacturing system to be operated profitably (in the short-term) with a various amount of volume for several products without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.***

In contrast to volume flexibility, expansion flexibility is not confined to the current resources available and is related to increasing the capacity or capability of the manufacturing system in the long-term (Sethi & Sethi, 1990; Chen *et al.*, 1992). The long-term horizon of expansion flexibility allows changes in the number of machines and technological advancements to be made in the meantime. The number and variety of expansions that can be accommodated for a particular manufacturing system indicate the levels of range-number and range-heterogeneity. Transition penalties could include the time needed to add a new machine and to restart the production system and should be used to determine the level of mobility. Performance outcomes include efficiency, manufacturing costs and quality level of the output that should be observed in order to derive the level of uniformity. Based on this description, the following definition of expansion flexibility is proposed:

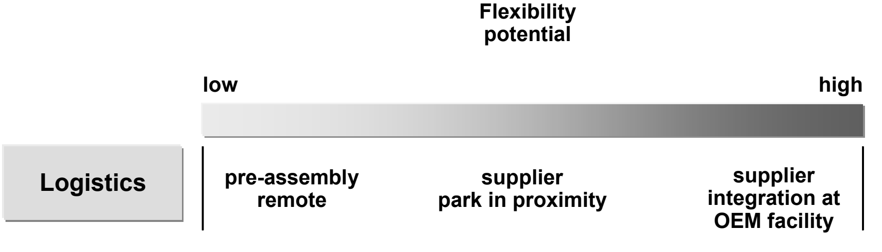
> ***The ability of a manufacturing system to accommodate a number and a variety of expansions without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.***

Quinn (1980) suggests that several measures can be taken in order to increase the level of volume and expansion flexibility. First of all, organisations should establish so-called 'horizontal scanning activities' can that identify the general nature and extent of the most likely opportunities and threats the organisation might encounter. Second, small resource buffers allow a more effective response as changes in demand occur. It should be noted that this measure contradicts the lean production philosophy and confirms research findings of Oliver *et al.* (1994) and Lin & Hui (1999) (see paragraph 2.2). Third, in order to utilise opportunities, organisations need to develop 'credible activists' whose role it is to press proactively for movement as opportunities or threats develop (Volberda, 1999).

3.4.3 Logistical flexibility

Logistical flexibility refers to the ability to supply modules in a very short time interval when disturbances occur (Rieken, 1995). The extent of logistical flexibility achieved is primarily determined by the physical proximity of the supplier to the OEM and can be depicted along a continuum (see figure 3-4).

Figure 3-4: Logistical flexibility potential



With the increasing physical distance between buyer and supplier, the JIT factor becomes more critical. In contrast to the remote assembly of modules, a supplier park in the proximity of the OEM not only offers the advantages of a shorter transport distance, but also the possibility to use synergies among suppliers such as joint stocking facilities and shared administrative tasks. When suppliers are integrated into the assembly facilities of the OEM, the highest level of logistical flexibility (and process stability) is achieved since the physical distance is reduced to the minimum.

This dimension observes the planning and control of the inbound and outbound flow of goods, from the disposition of the goods at the supplier to the delivery at the assembly line of the OEM. A rigid functional separation between in- and outbound flexibility leads to design problems of the logistical function and difficulties in grasping the level of flexibility (Striening, 1991; Horvath *et al*., 1993).

The range can be captured by the number and variety of logistical tasks performed. Fluctuations in the delivery accuracy give an indication of the transition penalties that are incurred and indicate the height of the mobility. Performance outcomes include logistical costs and quality levels that should be observed in order to derive the level of uniformity. In accordance with the description above, the following definition of logistical flexibility is offered:

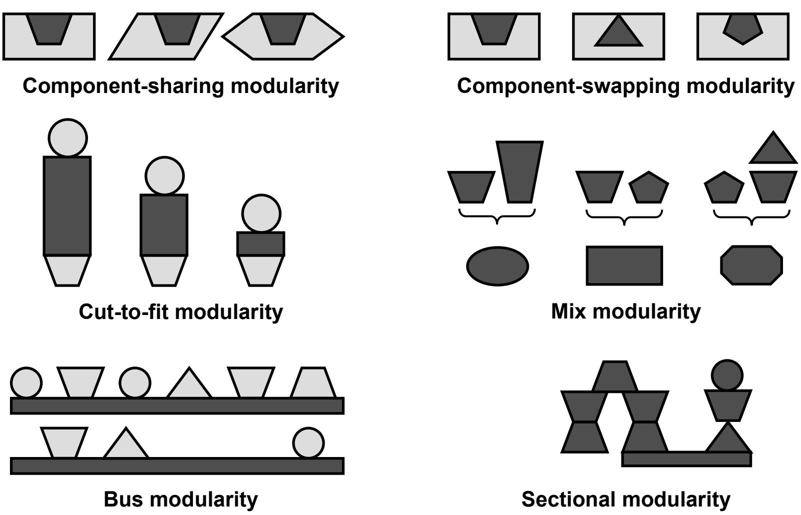
> ***The ability to control and execute a number of logistical tasks both inbound and outbound with a large variety without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.***

3.4.4 Product flexibility

Product flexibility refers to the ease with which specifications can be changed for newly introduced or existing products and has been frequently studied in both conceptual (e.g. Piller, 1998; Piller & Waringer, 1999) and empirical research (e.g. Gupta & Somers, 1992; Tsourveloudis, 1997; Koste, 1999). A product is considered new if its functional characteristics are not the same as those of any other product made previously (Dixon, 1992; Suarez *et al.*, 1995). Similarly, a modified product can be defined as having maintained the same functional characteristics as the previous product (Dixon, 1992).

The variety of products offered and the ability to adjust their functionality determine product flexibility. The application of modular product architecture is for many OEMs the basis for increasing the variety and flexibility without creating massive upheavals in costs. Such modular product architecture can vary from simple forms, without really changing the nature of what is being produced, to those that allow individual customisation and fundamentally change the design of the product. In figure 3-5 a typical classification of modular product architectures is displayed based on Abernathy & Utterback (1978).

Figure 3-5: Classification of modular product architectures



Component sharing/swapping modularity refers to the use of the same component across multiple product ranges. The ‘core‘ module is standardised and can be used in an entire product line. This form is applied when the costs of the different products in one particular product line are rising as rapidly as the number of product varieties. Cut-to-fit modularity refers to the use of one or more components that are continuously variable within pre-set limits. Furthermore, mix modularity refers to the use of a combination of component sharing/swapping and cut-to-fit modularity. A bus structure is a standard structure to which a number of different components can be attached. Finally, sectional modularity refers to the ability to configure any number of different types of components in arbitrary ways with the condition that each component is connected to another at standard interfaces. This type of modularity provides the largest degree of variety and is primarily used in the computer hard and software industry.

In the automotive industry, relatively standardised products are used which vary only minimally in local markets. For this reason, primarily component sharing and swapping modularity are used for different vehicle models in combination with product platforms. It should be noted that consumers could perceive some sets of modularised products as too similar (Pine, 1993). For this reason, it is important that the part of the product what consumers finds most personal, should retained the most variable[25].

The capability of making functional or engineering changes can be determined by observing the ability to handle difficult, non-standardised orders. Furthermore, the ability to add or substitute new parts gives an indication of this capability as well (Gupta & Somers, 1996). Moreover, the number of new products or modifications an organisation introduces indicates the range-number. The range-heterogeneity is related to the novelty of the products introduced or the modifications made to existing products. The time and costs that are required to prepare a new product mix could indicate the transition penalties that are incurred which determine the level of mobility. It should be noted that the development time and costs are likely to be higher for new products than for existing modified products. Therefore, a relative transition penalty should be observed for which benchmarks could be used. The similarity of performance outcomes can be captured through quality levels and efficiency in the development and indicate the level of uniformity. In accordance with the description above, the following definition of product flexibility is offered:

> ***The number and heterogeneity of newly introduced products or modifications on existing products that are achieved without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.***

3.4.5 Machine flexibility

Machine flexibility refers to the ability to perform multiple activities on a machine and has been studied quite extensively in both conceptual (e.g. Rieken, 1995, Wolters, 1995) and empirical research (e.g. Sethi & Sethi, 1990). Based on the contemplation model as developed by Moerman (1998), a machine flexibility continuum for was developed (figure 3-6).

The most advanced technology can be found in universally applicable machines that allow the production of a broad range of products. The use of multi-purpose machines allows a somewhat reduced variety of product to be produced, but with less set-up time as compared to specialised machines. The latter mentioned types of machines perform highly specialised operations and usually have long re-tooling times.

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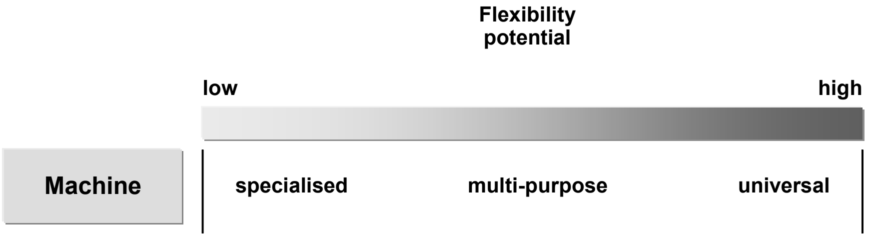
[25] For a vehicle are only a few components critical to a purchase (body style, engine, exterior colour and type of radio). Yet OEM's have often been investing in increasing the variety of options that customers do not perceive critical.

Figure 3-6: Machine flexibility potential



Machine flexibility is mainly determined by existing hardware and the space availability on the shop floor. The use of universal machines allows a rapid adaptation to a different assembly task (increase of range-number) at low costs because of reduced re-tooling times (Nof *et al.*, 1996). Re-tooling times refer to the time required to replace worn out or broken tools and assemble or mount the required fixture. The use of simplified components in machines in turn largely determines these re-tooling times and not only applies to the actual assembly stations but also to the inter-linkage of machines (Spingler & Bäßler, 1984).

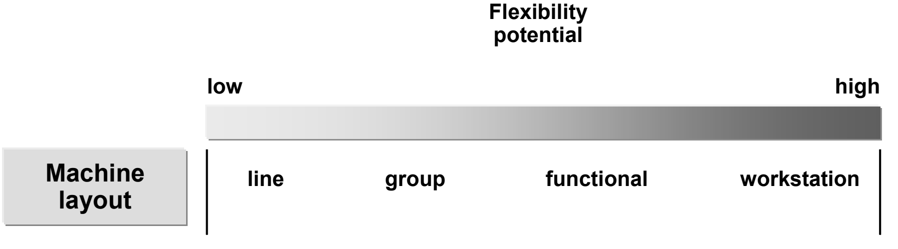
The number of operations a particular machine can perform indicates the range-number. Furthermore, the variety of operations without requiring a prohibitive effort in switching from one operation to another specifies the range-heterogeneity. The physical characteristics of a machine such as number of motion axes, maximum accuracy, as well as with the diversity of work pieces on which the machine can operate, indirectly indicates the level of range-heterogeneity (Koste, 1999). The time required to change the operations for a particular machine is a possible transition penalty that determines the level of mobility. Finally, performance outcomes include efficiency, manufacturing costs and quality levels that can be used to determine the level of uniformity. In accordance with the description above, the following definition of machine flexibility is proposed:

The number of operations and the variety of products that can be produced with the use of a machine without incurring negative effects (e.g. time-delays, changes in performance outcomes) when switching from one operation to another.

Technological developments are enhanced by simultaneous developments in information technology. For example, flexible manufacturing systems (FMS) involve the use of computer numeric controls (CNC) and robotics to create flexible machines that are able to produce a wide range of products with a minimum of manual intervention. Linking these applications with computer-aided manufacturing (CAM) enables processes to be run directly from CAD-product design files (Sanchez, 1995). These applications have challenged the long held belief that higher levels of automation are less flexible in nature. Therefore, the continuum of process flexibility as depicted in figure 3-6 is only valid at a given technological level.

In determining the level of flexibility, not only the machines, but also the inter-linkage between machines needs to be observed. In figure 3-7 a machine layout flexibility continuum is depicted based on a compilation of the workflow rigidity dimensions of Hickson *et al.* (1969) and Volberda (1999).

Figure 3-7: Machine layout flexibility potential



In the line layout, machines are serially structured to enable operations to be executed in the same strict sequence using different means of production (van Donk, *et al.*, 1991). This layout is very efficient in a stable environment and allows the highest throughput time possible. On the other hand, this type of layout has a low flexibility potential since it is very sensitive to disturbances. In a group layout, machines are structured according to the similarity of products. In contrast, in the functional layout, machines are grouped according to the similarity of methods and techniques (Moerman, 1998). Finally, in a workstation layout, 'mini plants' inside the manufacturing system operate completely independent of each other, which entails the highest level of flexibility (Moerman, 1998).

The changeability of the design and configuration is an important measure in order to determine the level of machine layout flexibility. Hill (1983) argues that it is necessary to include some slack in the layout design in order to reduce the need for redesigning production facilities when operations change. For instance the 'cross' outline of the production facility of DaimlerChrysler in

Hambach (France) where the SMART is produced allows the extension of the assembly line with little effort.

3.4.6 Personnel flexibility

In this study personnel flexibility includes both numerical and functional flexibility and has been studied in conceptual (e.g. Huyn & Ahn, 1992) and empirical research (e.g. Gupta & Somers, 1992, 1996; Koste, 1999).

Numerical flexibility refers to the ability of organisations to adjust the number of workers or the level of hours worked in line with the organisation's workload (Atkinson, 1987). For example, overtime can be used to adjust the number of working hours without hiring additional employees. Furthermore, the following other leverages that can enhance the numerical flexibility as well: flexible pensioning, the use of exployment/outsourcing, temporary contracts, and part-time employment (Van Ham *et al.*, 1986). However, organisations do not always look for additional personnel per se. It may be possible that there is a temporary shortage of personnel capable of performing one task, while simultaneously there is a surplus of employees that perform other tasks. Hence, the organisation can decide to train its employees to master multiple tasks thereby increasing the functional flexibility of personnel. In other words, the readiness of personnel to perform different tasks is enhanced in response to varying business demands (Atkinson, 1985). Horizontal training programs aim at developing skills for performing a wide variety of different tasks, rather than increasing specialisation of work. The workforce learns how to perform a number of tasks in multiple functional departments instead of only one. Job rotation involves a deliberate plan to move workers to various jobs on a consistent, scheduled basis.

Numerical and functional flexibility are highly interrelated and their level depends on the cultural context. After an empirical study, Morroni (1991) concluded that Japanese firms were only able to achieve higher levels of functional personnel flexibility (e.g. transferring employees to various tasks within the organisation) by limiting their workers' external mobility (numerical flexibility). On the other hand, European organisations use a combination of functional and numerical flexibility in order to adopt to demand changes. The European measures are compensated for by a comparatively rigid social system that guarantees a network of protective measures such as opportunities for retraining and unemployment benefits.

The number and variety of tasks performed indicate the level of range-number respectively range-heterogeneity. Transfer times and cost indicate the transition penalties, which determine the level of mobility. Finally, changes in performance outcomes can be assessed by the quality and efficiency levels, and indicates the level of uniformity. In accordance with the description above, the following definition of personnel flexibility is proposed:

> ***The ability to adjust the number of employees and tasks, including the variety of tasks (heterogeneity), without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.***

3.5 Manufacturing flexibility hierarchy

So far, empirical studies (Brown *et al.,* 1984; Hyun & Ahn, 1992; Upton, 1994; Koste, 1999) have created manufacturing flexibility classifications that are either time or hierarchy based.

A typical time-based classification consists of an operational, tactical, and strategic time horizon (Upton, 1994). The operational flexibility dimensions refer to day-to-day changes, whereas tactical flexibility addresses occasional change. Finally, the strategic dimension reflects the change that occurs once in a period of several years. These time periods depend on when the information initiating a flexible response, becomes known. Yet, a clear separation of the time intervals cannot be made and therefore lacks generalisability across organisations (Koste, 1999).

A hierarchical flexibility classification is based on relationships between flexibility dimensions. Moreover, this type of classification identifies those flexibility dimensions that serve as building blocks for others. Research conducted by Hyun & Ahn (1992) and Koste (1999) shows that lower hierarchical levels are related to technological aspects, whereas higher levels result from combining lower levels with new capabilities. In this study a hierarchical classification of flexibility dimensions is developed which corresponds to the primary level analysis. Before presenting this hierarchical classification of manufacturing flexibility, the developed hierarchies of Hyun & Ahn (1992) and Koste (1999) are examined.

Hyun & Ahn (1992) observe a business, functional, and component level, which is based on the observation that various concepts of flexibility result essentially from different viewpoints. First of all, in the systems view, flexibility is observed as a system-component that reflects the organisational structure. Second, in the environment-associated view flexibility is related to the environmental characteristics surrounding the manufacturing system. Finally, a decision hierarchical view observes the long-term (strategic), mid-term (tactical), and short-term (operational) time horizon, which corresponds to a time-based classification as described before. Hyun & Ahn (1992) conclude that the observed levels are not conflicting; rather they help to integrate different views on manufacturing flexibility in a consistent manner. On the observed business level, manufacturing flexibility is considered as a means to achieve a competitive advantage. Furthermore, manufacturing flexibility exists among other functionally oriented flexibility dimensions such as marketing and R&D flexibility. In addition, manufacturing flexibility depends on lower level component flexibility dimensions, such as machine, routing, and control flexibility.

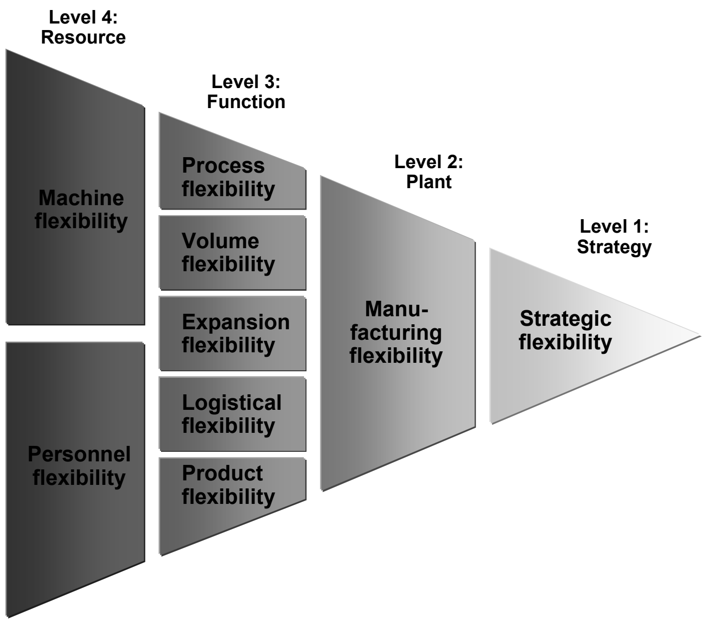
Despite their contribution to a better understanding of relevant viewpoints and dependence between different levels, Hyun & Ahn (1992) failed to include the hierarchical relationship between machine and routing flexibility. These two flexibility dimensions are observed on the same hierarchical level suggesting that no hierarchical relationship exist. However, several researchers (e.g. Sethi & Sethi, 1990; Koste, 1999) provided strong empirical evidence that machine flexibility is a basic building block for routing flexibility. As a result, machine flexibility should be placed lower in the hierarchy than routing flexibility.

Koste (1999) distinguishes five hierarchical levels of flexibility that are partly based on the work of Hyun & Ahn (1992). The two top levels (strategic and functional flexibility) are similar to the distinction of Hyun & Ahn (1992), even though different terms are used. The third level (plant level), fourth level (shop floor level) and fifth level (individual resource level) correspond to the component level in the hierarchy of Hyun & Ahn (1992). However, the five hierarchical levels Koste (1999) distinguishes are neither consistent. For instance, material-handling flexibility is considered on the same hierarchical level as machine and labour flexibility; yet, these two flexibility dimensions at the same time determine material-handling flexibility. In other words, machine and labour flexibility serve as building blocks for material-handling flexibility and therefore should be considered on a lower hierarchical level.

In figure 3-8 the manufacturing flexibility hierarchy is displayed. This hierarchical classification observes four levels and is influenced by the work of Hyun & Ahn (1992) and Koste (1999). The two building block levels of manufacturing flexibility try to overcome the interpretation problems from previous studies.

On the strategic level, organisational flexibility in response to market changes is observed, which is similar to the distinction of Hyun & Ahn (1992) and (Koste 1999). Strategic flexibility has been the subject of many publications and determines the overall flexibility that is achieved by an organisation (see paragraph 3.2). A flexible organisation possesses a set of different strategic options that allow an effective response in dynamic competitive environments. The extent of strategic flexibility primarily depends on managerial policies and investment decisions.

Figure 3-8: Manufacturing flexibility hierarchy



On the plant level, manufacturing flexibility is considered as equally important to strategic flexibility as other dimensions such as R&D flexibility, marketing flexibility, and sales flexibility. In this study, manufacturing flexibility is broadly defined as:

> ***"… the ability to change or react with little penalty time, effort, cost or performance… (Upton, 1994, p. 73)"***

Manufacturing flexibility builds on specific plant functions and resources in order to support the strategic level. Level three and four jointly comprise the entire domain of manufacturing flexibility. On the functional level the following five dimensions are observed: process flexibility, volume flexibility, expansion flexibility, logistical flexibility, and product flexibility. An organisation will use the appropriate mix of these dimensions it deems necessary. Every organisation possesses a different level of a given flexibility capability (Koste, 1999). These mixes may vary for organisations that produce different sets of products and can be a basis for a competitive advantage. Finally, machine and personnel flexibility make up the resource level and are considered as building blocks for the other higher-level flexibility dimensions. Relationships among the dimensions at the same level may or may not exist, they are considered given in this study. It should be noted that these different flexibility dimensions will exist for all supply chain parties to some extent. The full spectrum of the dimensions is likely to be represented by the entire supply chain.

Since the lower-level flexibility dimensions serve as building blocks, they can be regarded as constraining factors for manufacturing flexibility. For instance, when a machine reaches the boundaries of its capacity, alternate processing plans can be used to re-direct the flow of the goods. This suggests that machine flexibility supports process flexibility. Routing flexibility relies on the existence of machine flexibility as well (Sethi & Sethi, 1990; Koste, 1999). Furthermore, machine flexibility is considered vital to volume flexibility since the capacity of flexible machines can be used for other production volumes as well (Suarez *et al.*, 1995). In addition, several empirical studies (Sethi & Sethi, 1990; Chen *et al.*, 1992; Hyun & Ahn, 1992) indicate a correlation to some extent between machine and expansion flexibility. Conceptual support exists for machine flexibility and logistical flexibility (Eicke & Femerling, 1991; Gries, 1994; Wolters, 1995), although empirical evidence is lacking. Finally, machine flexibility is often cited as the building block for product flexibility (e.g. Beckman, 1990; Chen *et al.*, 1992; Hyun & Ahn, 1992; Suarez *et al.*, 1995). Machines that can be universally applied may be able to process different products and thus reduce the need to acquire new machines.

Personnel flexibility has some supportive relationships with higher-level flexibility dimensions as well. Even though personnel flexibility has not been studied in relation to routing aspects of process flexibility, some conceptual supports exists (Koste, 1999). Personnel that are familiar with a number of different tasks are more creative in finding alternate routing paths in the case of malfunction. Conceptual support exists for the relationship between personnel flexibility and volume flexibility (Chen *et al.*, 1992; Huyn & Ahn, 1992; Suarez *et al.*, 1995), yet further empirical research is necessary. Hyun & Ahn (1992) confirmed the expected relationship between personnel and expansion flexibility, since increases in functional flexibility could reduce the need for additional machines in the future. Finally, conceptual support for the relationship between personnel flexibility and logistical flexibility is available (Eicke & Femerling, 1991; Wolters, 1995) as well as for the relationship between personnel flexibility and product flexibility (Chen *et al.*, 1992; Huyn & Ahn, 1992).

3.6 Conclusions

In this chapter, manufacturing flexibility has been extensively analysed, as a basis for the development of the conceptual framework. Based on the analysis key manufacturing flexibility publications, it was concluded that many definitions, as well as a variety of dimensions, are available. Yet, these dimensions are often confusing and have a tendency to focus on the internal organisation only. Moreover, the different dimensions are not clearly specified, resulting in a high extent of overlap and confusion. For a more comprehensive domain specification, four elements were defined and included in the description of every flexibility dimension. The 'range-number' refers to a strict numerical count of the number of possible options that a system or a resource can achieve. The 'range-heterogeneity' describes the degree of difference between these alternatives. 'Mobility' refers to the ease with which an organisation moves from one state to another. Finally, the similarity of performance outcomes is referred to as 'uniformity'. Based on these elements, seven (process, volume, expansion, logistics, product, machine, personnel) flexibility dimensions were defined. These dimensions were used to develop a flexibility hierarchy in which lower level dimensions are considered as building blocks for the higher levels. The presented manufacturing flexibility hierarchy consists of four levels. The first level represents the strategic level and determines the overall flexibility that is achieved by an organisation. On the plant level, manufacturing flexibility is considered equally important to strategic flexibility as other dimensions such as R&D flexibility, marketing flexibility, and sales flexibility. The functional level observes process flexibility, volume flexibility, expansion flexibility, logistical flexibility, and product flexibility. Finally, the resource level consists of machine and personnel flexibility that are considered as basic building blocks for other levels in the hierarchy.

4 Conceptual framework & research design

Case studies research often entails interviewing and archival skills and an ability to see patterns amid masses of data that may be incomplete and distorted by perceptions and politics. In other words it is not necessarily an efficient form of research. However, more efficient methods must constantly rely on such techniques as case study research to ensure that our theories, experiments and advice to managers do not become detached from reality.

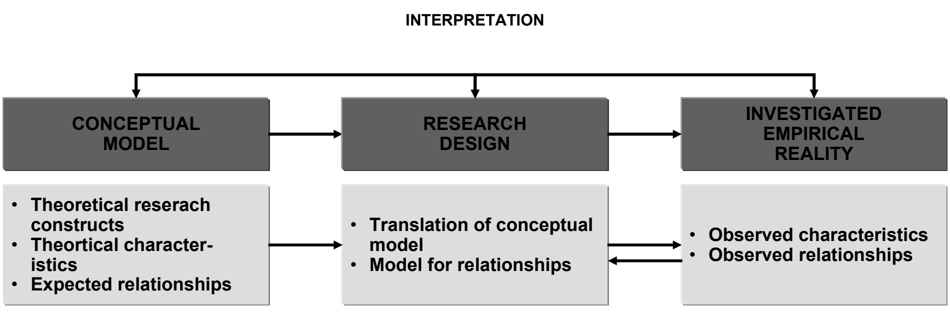
(McCutcheon & Meredith, 1993, p. 255)

4.1 Introduction

In this chapter, the conceptual framework for this study is presented including the research design necessary to validate this framework. The conceptual framework as presented in paragraph 4.2 is a translation of the expected relationships between the research constructs as described in chapters 2 and 3. In paragraph 4.3 the research strategy is presented that builds a bridge between conceptual ideas and the empirical reality. For the exploration and validation of the conceptual framework both case study research (paragraph 4.4 and paragraph 4.5), and survey-based research (paragraph 4.6) are used. Finally, paragraph 4.7 summarises the most important conclusions of this chapter.

The relationship in the research process between the conceptual model, research design, and investigated empirical reality is depicted in figure 4-1 and is based on Riley (1963).

Figure 4-1: Research process



After formulating the research questions, the researcher tries to develop a theoretical framework of which is expected to elucidate the research constructs, theoretical characteristics, and relationships. Such a theoretical framework can be built based on existing theories including additions. In terms of Riley (1963), the research constructs are placed in a conceptual model for which, implicitly or explicitly, certain theories are selected that preliminarily answer the posed research questions. The theories used in this conceptual model are expected to be of a preliminary and hypothetical nature.

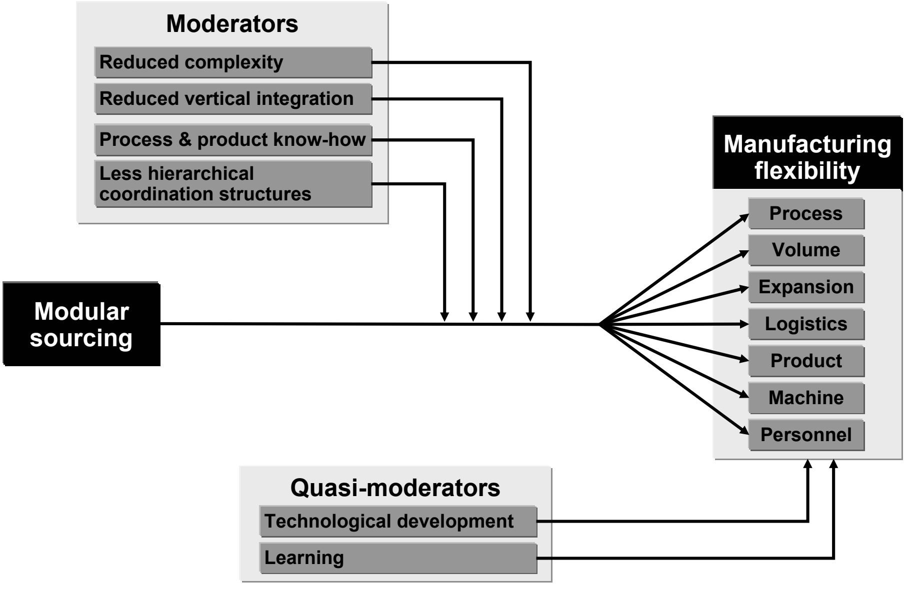
The research process starts by placing the problem definition in a conceptual framework. Of central importance in the research process is the confrontation of the theoretical ideas with the empirical reality. The key for comparing the expected versus real relationships is the research design. In other words, the explicit elaboration of the research design and associated choices are prerequisites to comprehending how theory is confronted with practice (Swanborn, 1987).

4.2 Conceptual framework

A primary component of a conceptual framework is a variable, which can be regarded as the characteristics of the research subject (Swanborn, 1987). So-called 'specification variables' describe the relationship between the independent (=modular sourcing) variable and dependent (=manufacturing flexibility) variable (Rosenberg, 1968). In accordance with Sharma *et al.* (1981), so-called 'moderating' variables are identified in this study that influence the relationship between modular sourcing and manufacturing flexibility. Furthermore, quasi moderators are almost identical to (pure) moderators with the difference that they can be considered as a predictor variable as well in the studied relationship (Sharma *et al.*, 1981). In other words, quasi-moderating variables may affect the manufacturing flexibility achieved and are not related to modular sourcing.

Relationships form a second component of the conceptual framework and indicate the dependence among the variables (Van der Velde *et al.*, 2000). Insight into these relationships is the primary driver for empirical research (Swanborn, 1987). As a part of these relationships, propositions are made that indicate the expected relationship between modular sourcing (A) and manufacturing flexibility (B). This relationship is symbolised as 'A → B', in which the direction of the arrow represents the cause and effect. For this study, it is important to observe that exploratory research is used to indicate such as relationship. Direct causal research between measurable improved manufacturing flexibility and the application of modular sourcing would require longitudinal research. Even if longitudinal research would be applied, the direct cause-and-effect relationship between modular sourcing and improved manufacturing flexibility would still be questionable, since other quasi-moderating variables (non-modular sourcing related) could have caused an increased level of flexibility as well. Therefore, the relationship between modular sourcing and manufacturing flexibility is described as 'A is positively related to B' and not 'A causes B'. The conceptual framework for this study is depicted in the figure 4-2.

Figure 4-2: Conceptual framework



In this conceptual framework, the primary relationship between modular sourcing and the described dimensions of manufacturing flexibility is displayed. The inclusion of seven dimensions corresponds to the general understanding of manufacturing flexibility as a multi-dimensional concept (e.g. Sethi & Sethi, 1990; Gupta & Somers, 1992). In the definition of the domain of manufacturing flexibility, insights from the key publications of Gupta & Somers (1992), Dixon (1992), Hyun & Ahn (1992), and Koste (1999) were included.

These dimensions of manufacturing flexibility are likely to be influenced by modular sourcing applications. For this reason the following propositions are offered:

Proposition 1a: **Modular sourcing has a positive effect on the level of process flexibility achieved.**

Proposition 1b: **Modular sourcing has a positive effect on the level of volume flexibility achieved.**

Proposition 1c: **Modular sourcing has a positive effect on the level of expansion flexibility achieved.**

Proposition 1d: **Modular sourcing has a positive effect on the level of logistical flexibility achieved.**

Proposition 1e: **Modular sourcing has a positive effect on the level of product flexibility achieved.**

Proposition 1f: **Modular sourcing has a positive effect on the level of machine flexibility achieved.**

Proposition 1g: **Modular sourcing has a positive effect on the level of personnel flexibility achieved.**

These relationships will be explored in the exploratory case studies (chapter 5) and are validated a survey (chapter 6). If the relationship between modular sourcing and manufacturing flexibility were confirmed by exploratory as well as the survey-based research, more conclusive findings could be formulated (see paragraph 4.3). In addition, the case studies focus on several moderator variables that are expected to influence the relationship between modular sourcing and manufacturing flexibility.

In the light of several economic theories such as scientific management (Taylor, 1947), classical administrative theory (Fayol, 1947), classical economic theory (Adam Smith, 1776), and the contingency theory (Woodward, 1965) the initial rationalisation of manufacturing operations has been discussed. Based on these theories, it was concluded that traditional methods, organisational structures, and routine responses were no longer working properly because of the increasing environmental turbulence. Based on this, the reduction of the extent of complexity for OEMs has been identified as a moderating variable. A reduction of the extent of customer, product program, and manufacturing system complexity is likely to positively influence the relationship between modular sourcing and manufacturing flexibility. Second, in the efforts to reduce the level of complexity and increase the flexibility of the manufacturing system, the extent of vertical integration is reduced. Therefore, the extent of vertical integration is considered a moderating variable as well. Third, a high level of supplier process and product know-how is expected to influence the relationship between modular sourcing and manufacturing flexibility as well. Finally, less hierarchical coordination structures are expected to positively influence the relationship between modular sourcing and manufacturing flexibility. The uncertainty about the value of investments and getting access to the suppliers valuable, hard to imitate and costly capabilities despite the threat of opportunism is expected to dominate governance choices. Summarising these arguments the following propositions are offered:

Proposition 2a: Complexity reduction of the OEM positively influences the relationship between modular sourcing and manufacturing flexibility.

Proposition 2b: A reduced extent of vertical integration positively influences the relationship between modular sourcing and manufacturing flexibility.

Proposition 2c: Process and product know-how of a supplier positively influences the relationship between modular sourcing and manufacturing flexibility.

Proposition 2d: Less hierarchical coordination structures between the OEM and supplier positively influence the relationship between modular sourcing and manufacturing flexibility.

In the case studies quasi-moderating variables are observed as well since it is very likely that other variables than modular sourcing affect the level manufacturing flexibility achieved. These quasi-moderating variables have been identified based on the resource-based theory of the firm (Penrose, 1959; Learned *et al.*, 1969; Barney, 1991). First of all, technological developments are often implemented to improve the flexibility of the manufacturing system. These developments can include, a wider range of products that can be produced on the same machine, a reduction of set-up and retooling times, and increased throughput time. Second, learnings that are made when more volume is produced can improve the flexibility of a manufacturing system as well. This effect is derived from the so-called ‘learning curve model’ (Henderson, 1974) and is based on the observation that the costs of producing a unit of output falls as the cumulative volume is increased. The logic behind this curve is relatively straightforward. It is clear that the first organisation that moves down the learning curve will obtain a cost advantage, which is reflected by a higher performance level of the manufacturing system. It should be noted that that this argumentation assumes that the products produced are immediately sold to customers. Manufacturing to increase inventory may reduce the production costs but will lead to the negative performance of the organisation as a whole. Thus, to go down the learning curve and obtain cost advantages, organisations must aggressively acquire market share. Summarising these arguments, the following propositions are offered:

Proposition 3a: Technological developments positively influence manufacturing flexibility.

Proposition 3b: Learning made positively influence manufacturing flexibility.

4.3 Research strategy

Both exploratory case studies and survey-based research are used to investigate the relationship between modular sourcing on manufacturing flexibility. The main reason for using exploratory case studies is the fact that the interest is not just empirical. The conceptual model as developed in paragraph 4.2 is merely conceptual and, as such, has a tentative and hypothetical status (Segers, 1977).

The use of both exploratory case studies and survey-based research is in alignment with the insights from triangulation[26]. Triangulation is a convergent methodology based on the conception that qualitative and quantitative methods should be viewed as complementary (Yin, 1994). The mix of methods allows the researcher to draw upon the paired strengths of the methods used. In addition to this, Jick (1979) states that the most prevalent use of triangulation is in efforts to integrate fieldwork and survey methods.

The application of multiple methods not only increases the accuracy of the study, but also allows the formulation of more conclusive findings if the applied methods lead to similar conclusions. Triangulation can also be used within the research methodologies to combine modes of data collection or the methods of validating and testing scales (Eisenhardt, 1989; Ellram, 1996). Finally, the use of multiple methods can lead to the synthesis of theories from different functional backgrounds such as logistics, marketing and shop floor design.

McClintock *et al.* (1979) state that the spread of research methodologies contribute to the basic research goals of generalisability, accuracy, and simplicity. Furthermore, McClintock *et al.* (1979) argue that one research methodology can maximally achieve two of these goals mentioned, which suggests that trade-offs

[26] Triangulation in the pure form entails the use of tree different methods.

have to be made. Case studies are relatively accurate and try to simplify the phenomenon being studied. In addition to this, a strong feeling for the subject of study is developed (Selltiz *et al.*, 1976). Therefore, exploratory case studies are conducted to gain initial insight into the effects of modular sourcing on manufacturing flexibility. On the other hand, survey-based research is applied to generalise the findings of the exploratory cases studies concerning the main research construct. In this type of research, a multi-item scale needs to be developed before the propositions can be validated.

4.4 Case study research

Exploratory research is particularly helpful in breaking down broad problem definitions into smaller, more precise sub-problem statements. In the early stages of research, the lack of sufficient understanding of the problem prevents the formulation of strong findings. Often tentative explanations are given for specific phenomena, which should be avoided. Case study research can be used to gather information about the practical problems of carrying out research on particular conjectural statements (Selltiz *et al.,* 1976). Since there is a lack of knowledge at the start of the investigation, exploratory studies are characterised by flexibility with respect to the methods used to gain insight. In addition to this, Yin (1994) states that case studies are particularly helpful when investigating:

> *"… a contemporary set of events, over which the investigator has little or no control (Yin, 1994, p. 20)."*

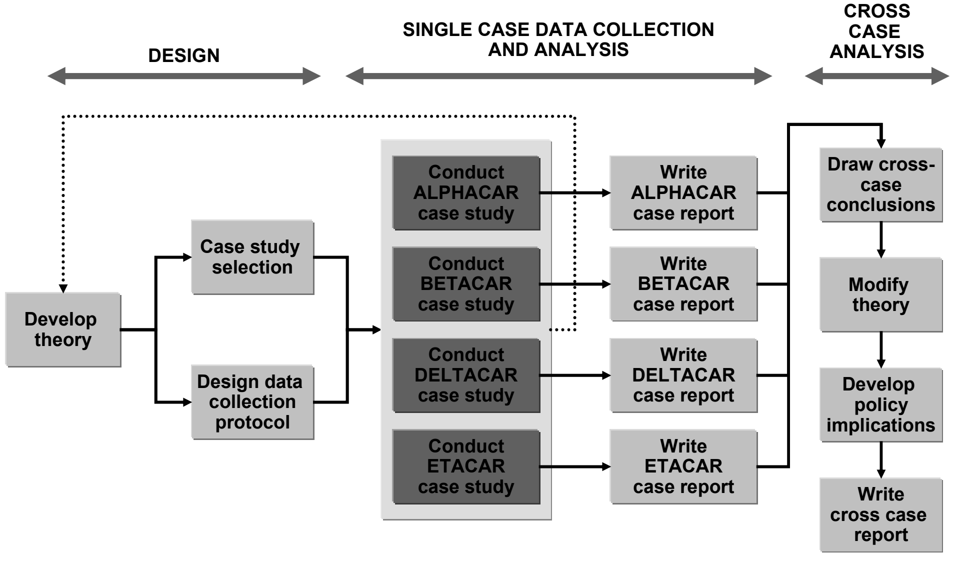
This study analyses decisions that are currently made - including decisions on modular sourcing activities. Besides contemporary events, this study also focuses on underlying factors such as resources, capabilities, and governance structures. If actors decide to change these decisions, the implementation and results of these changes are also subject to analysis since the dynamics of the implementation may lead to an adjustment of decisions. Furthermore, Yin (1994) states that case studies are particularly useful for theory development since:

> *"… the appropriately developed theory also is the level at which the generalisation of the case study results will occur (Yin, 1994, p. 38)."*

Yin (1994) refers to this as 'analytic generalisation', which implies that the findings are on the same analytical level as characteristics of a certain population in survey-based research. The case study research requires an account of the methods used for analysis to underpin the validity of the results. Orderly research and approach are necessary, but not sufficient; the research has to be verifiable as well.

Figure 4-3 provides a schematic overview of the case study research as applied in this study and is based on Yin (1994).

Figure 4-3: Case study research design



Before selecting the case studies and designing the data collection protocol, a theory has to be developed which reflects the chapters 2 and 3 in this study. Each conducted case study consists of a 'whole' study, in which convergent evidence is sought regarding the facts and conclusions for the cases. For each of the individual cases, the report indicates how and why a particular hypothesis was demonstrated. Across the cases, the summary should indicate the extension of the replication logic.

If the research follows the above logic, can one be ensured that the derived conclusions on the effects of modular sourcing on manufacturing flexibility are reliable and valid? This question refers to the quality of the design based on four common criteria: 'construct validity', 'internal validity', 'external validity', and 'reliability' (Yin, 1994).

'Construct validity', refers to the establishment of correct operational measures for the concepts being studied. This concerns the specification of what is being studied: the effects of modular sourcing on manufacturing flexibility. Furthermore, as will be discussed in the following paragraph, multiple data-sources heighten the construct validity of current research.

‘Internal validity’, is concerned with the establishment of a causal relationship in which certain conditions are shown to have led to other conditions. Ideally, causal relationships are established by means of experiments in which all disturbing factors are excluded. In the research design, a careful matching procedure[27] is used to abstract from explanatory variables. Accordingly, the internal validity of this study is dependent on the accuracy of the matching criteria. To strengthen the internal validity of the research conclusions, the logic of the paired comparison is replicated (Yin, 1994). According to this principle, a conclusion is replicated if multiple cases demonstrate the same results.

‘External validity’, refers to the domain to which a study’s findings can be generalised. In case studies, one does not generalise from samples to larger universes, the generalisation is done from the results to some broader theory, which in turn is reflected by the conceptual model as developed in paragraph 4.2. Critics of case studies argue that the generalisability of their results is low because the evidence is based on a limited number of cases. However, such criticisms confuse analytical generalisation with statistical generalisation (Mitchell, 1983). Indeed, case studies are less suitable for statistical generalisation, that is, generalisation on the basis of a ‘sampling logic’. Such logic assumes that the selected sample represents a larger pool of subjects. Accordingly, data collected from the sample are assumed to reflect the entire universe or pool (Pot, 1998). In contrast, the rational for case studies lies in their potential for ‘analytic generalisation’ in which a particular set of results are generalised to some broader theory.

Finally, the criterion ‘reliability’ aims at minimising any errors and biases of the researcher in the execution of the case studies. The outcomes of a study can be called ‘reliable’ if the study can be conducted by other researchers without alteration of the results. Case study research is very vulnerable on this criterion because of their exploratory nature and lack of rigid procedures. In conducting case studies, socialisation efforts of the researcher are required. These efforts are likely to lead to new discoveries that could not have been anticipated beforehand. This subjective experience, inherent in case studies, makes replication difficult.

[27] Complete matching remains a practical impossibility. However, the advantage of case studies is the socialisation of the researcher in the natural context of the research objects that enable him to uncover the consequences of any imperfections in matching procedure (Pot, 1998).

Nevertheless, the reliability of findings is ensured by the development of a case study database and case study protocol (see paragraph 4.5).

4.5 Operationalisation of the case study research

Operationalisation refers to the link between the theory concerning case study design and the actual conducting of interviews, gathering of data, analysis and reporting. In this study, the guidelines as described by Ellram (1996) in the form of a case study 'protocol' are followed because of its practical orientation (see table 4-1). This protocol outlines the steps and procedures that were followed in the execution of the research.

Table 4-1: Case study protocol

STEPS	ELEMENT
1. Key research issues	Problem definition; specification of constructs
2. Methodology and design	Number of cases studies; sampling of interviewees
3. Sources	Documentation; direct observations; interviews
4. Outline of analysis / report	Overview, presentation and discussion of results
5. Timetable	Time table for case studies
6. Interview guide	Outline of the interview process

The (1) key research issues are specified prior to starting the case studies. The problem definition and specification of the research constructs help the research to keep efforts in line with the research questions. In chapter 1, the main research question was posed as well as three secondary research questions that help in answering the main question. Based on these research questions, modular sourcing and manufacturing flexibility were specified.

In the (2) case study methodology and design, the number of case studies and the sampling of interviewees need to be clarified. As described in chapter 1, this study primarily focuses on the German OEMs that are chosen for two major reasons. First of all, the setting in Germany, among the worlds largest and most successful OEMs, provides a unique view on technology-driven OEMs. To their success, modular sourcing contributed substantially. Secondly, German OEMs are considered to have the most experience in the application of modular sourcing and the corresponding supplier management (Eicke & Femerling, 1991; Wolters, 1995). For BMW, DaimlerChrysler, Porsche, and Volkswagen, case studies were conducted. These four OEMs will be randomly named ‘Alphacar’, ‘Betacar’, ‘Deltacar’, and ‘Etacar’ to ensure confidentiality.

In order to focus on manufacturing operations, specific plants were selected for a more detailed analysis[28]. The selected plants elucidate the different approaches towards modular sourcing applications that exist among German OEMs. The selected plants of Alphacar and Betacar can be considered as fairly conservative in their approach towards supplier integration. On the other hand, the observed plants for Deltacar and Etacar can be considered as more progressive since they have been experimenting with new supply chain configurations.

In the selection of knowledgeable interviewees, insights from different functional backgrounds such as R&D, purchasing, logistics, and production were considered important. Furthermore, a certain level of experience in supplier interaction was considered necessary. Several interviews with module suppliers were conducted to verify information and to gain insight into the role of modular sourcing and the increasing requirements from the suppliers’ side. An overview of respondents (n=24) according to the field of expertise is presented in table 4-2.

Table 4-2: Profile of interviewees

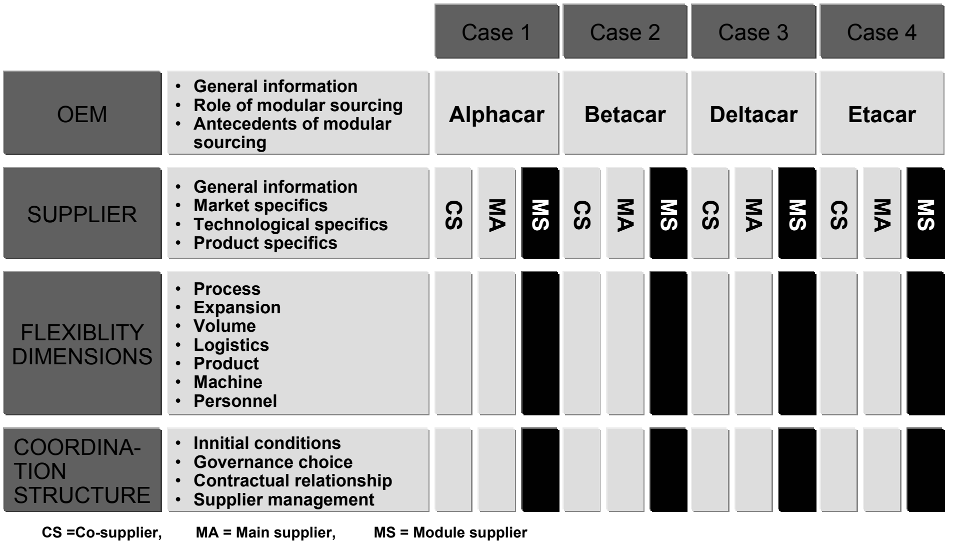
	ALPHACAR *(conservative)*	**BETACAR** *(conservative)*	**DELTACAR** *(progressive)*	**ETACAR** *(progressive)*
R&D / purchasing	n = 2	n = 3	n = 3	n = 2
Logistics / production	n = 2	n = 4	n = 5	n = 3

Several (3) sources of information, such as: publicly available material, interviews, aggregated confidential information and direct observations, were used in the analysis of the cases. Background information concerning the OEM and selected suppliers was acquired through desk research. Based on this information, additional data was collected through interviews with general and operational managers with different functional backgrounds. Also, available archives, financial statements and internal studies were used. Usually the type of data requested for analysis called for a compilation of (financial) data from different sources. Furthermore, experiences of other researchers and preliminary notions were also used to prepare semi-structured interview guidelines. Direct observations included local visits to the manufacturing facilities.

[28] In terms of the research design of Yin (1994), this refers to the unit of analysis.

The (4) outline of the case study analysis and the report is depicted in figure 4-4. The analysis of case studies typically goes through a stage of within-case analysis before it evolves into cross-case comparison. After analysing the direct effects of modular sourcing on manufacturing flexibility, the moderating as well and quasi-moderating variables were examined. After the in-depth analysis of the single cases, the comparison across cases was initiated. After sufficient information was obtained to explain the unique features of the cases, specific characteristics were selected that could be compared with other cases.

Figure 4-4: Outline of analysis and report



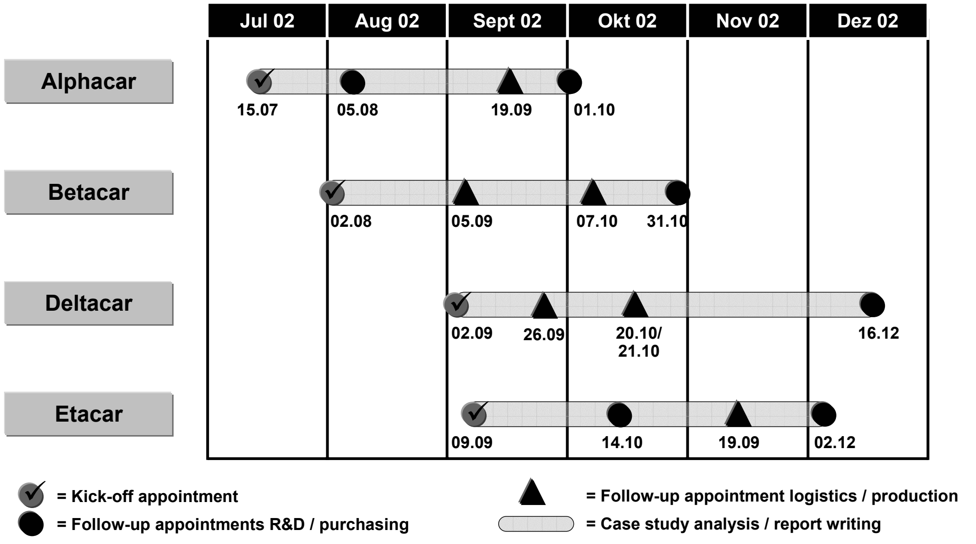
The aim of the cross case comparison was to seek explanations rather than testing them (Selltiz *et al.,* 1976). This cross-case search for patterns and explanations forces the researcher to go beyond initial impressions (Eisenhardt, 1989). Instrumentation is especially important for an adequate across case comparison and can be described as:

> *"… the kit of data-collecting devices that are keyed, directly or indirectly, to the conceptual framework and research questions (Miles and Huberman, 1984, p. 42)."*

In order to facilitate a cross case comparison, a certain amount of instrumentation has to be devised prior to the fieldwork. A checklist was developed in order to gather similar data across cases. Although cross case comparison is without doubt the foremost important reason for instrumentation, there are other reasons as well. First of all, prior instrumentation tends to raise the internal validity, enlarges the scope over which results can be generalised, and keeps the research itself manageable (Miles & Huberman, 1984). Secondly, from a more practical point of view, several interviewees required a list of questions before they agreed to cooperate.

The (5) time required to conduct the case studies was about 6 months and was initiated in July 2002 (see figure 4-5). For the interviews, a presentation that outlines this study was made and was refined several times. This presentation proved to be very helpful in conducting interviews and could be conducted in a (time-saving) parallel manner.

Figure 4-5: Case study planning



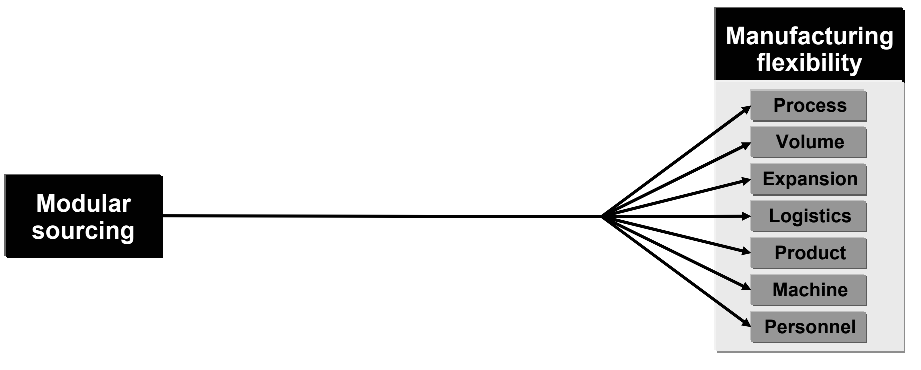
A (6) semi-structured interview guideline was used and was, when required, sent to the interviewees prior to the actual interview in order for them to prepare. In the actual interviews, a presentation provided a structured guideline and, at the same time, allowed enough room to make frequent changes in direction as new information appeared. Swanborn (1987) states that in the case of exploratory research, the collected data should be broad and abundant. Because of the semi-structured nature, the ample instrumentation did not hinder the exploratory character of the case studies. After conducting the interviews, a protocol was sent to the interviewees to check for misinterpretations. All interview protocols and available information was filed and catalogued in a case study database that formed the basis for writing the case study reports.

4.6 Survey-based research

After analysing the case studies, it was decided to focus on the most important relationships of the conceptual framework. In order to generalise the outcomes of relationships, a multi-item scale had to be developed which corresponds to the third research question (*How can manufacturing flexibility be measured?*).

Prior research on manufacturing flexibility provided many scale items that had to be analysed. This entailed a trade-off between the depth of the analysis and the length of the questionnaire. Consequently it was decided to focus the survey on the main research construct as depicted in figure 4-6.

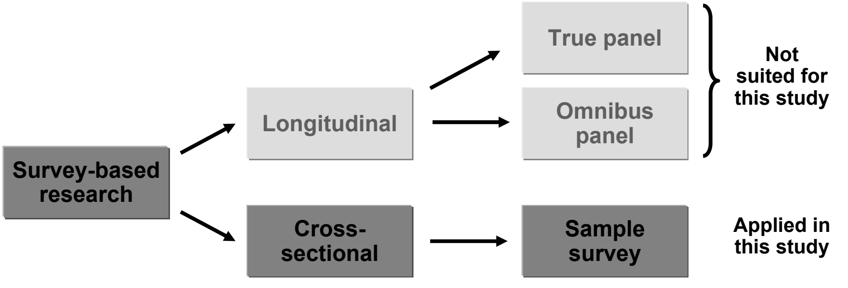
Figure 4-6: Main research construct



In the survey a non-existing relationship between the two research constructs was suggested at the start of the investigation. If this 'null' proposition is falsified, then the proposition, in which a positive dependent relationship is described, can be accepted. As described in paragraph 4.3, if the results are confirmed by case studies as well as survey-based research, stronger findings are provided.

In contrast to the flexible approach in exploratory research, survey-based research is considered more rigid. Figure 4-7 provides an overview of the different types of survey-based research that can be applied based on Churchill (1995).

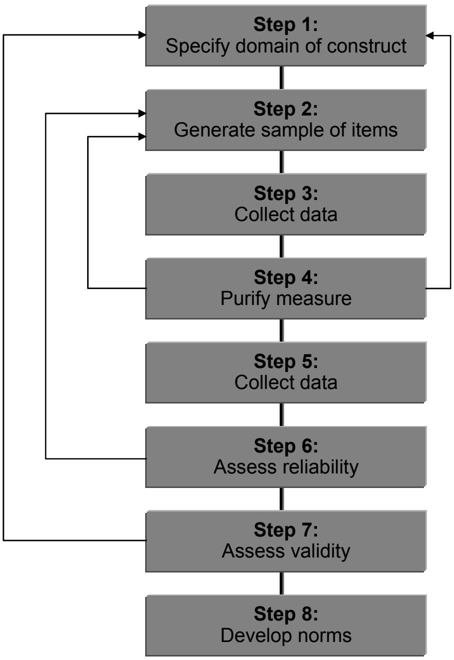
Figure 4-7: Overview of survey-based research



Cross-sectional research is primarily used to measure the various characteristics once, whereas longitudinal research considers the measurement over time. Furthermore, cross-sectional research involves a sample of elements from the population of interest, whereas true and omnibus panels are used in longitudinal research. Even though longitudinal research could be useful in observing manufacturing flexibility over time, there are some critical drawbacks to this method. The main disadvantage of panels is that they are non-representative (Churchill, 1995). Furthermore, the agreement to participate involves a far-reaching commitment of the respondent, which is very difficult to achieve. Instead, the use of cross-sectional research is far more useful in this study and is considered the most important type of survey-based research as measured by the number of times it is used as compared to other methods (Churchill, 1995). First of all, cross-sectional research provides a snapshot of the variables of interest at a single point in time. Second, the sample of elements selected are considered to be representative of some know universe (Churchill, 1995).

The multi-item scale has been developed using the framework of ‘better measures of marketing constructs’ (Churchill,1979) (see figure 4-8). This framework consists of eight steps that are necessary to develop a multi-item scale and is widely accepted by researchers (e.g. Flynn *et al.*, 1990; Langerak, 1997; Koste, 1999). Multi-item scales are recommended for capturing complex constructs and can be combined to allow the specificity of items to be averaged (Churchill, 1979). Furthermore, multiple items increase reliability and decrease the measurement error.

Figure 4-8: Survey-based research design



In the next paragraphs, elements of Churchill's framework are discussed in more detail. In paragraph 4.6.1 the domain specification, scale item development, sampling frame, and data collection are discussed. Paragraph 4.6.2 discusses the structure of the questionnaire and the pre-testing in two phases.

4.6.1 Operationalisation of the survey-based research

The first step of Churchill's framework involves the specification of the domain of the research constructs. In specifying the domain it is important that:

> *"… the researcher must be exacting in delineating what is included in the definition and what is excluded… (Churchill, 1979, p. 67)".*

The constructs as defined in chapters 2 and 3 need to be validated in order to develop items that describe these respective domains. Both literature research and expert opinion surveys are used for this validation. This is in accordance with the insights from triangulation that states that a combination of methods provides the basis for a more solid domain definition. After the domain validation, items for the research constructs were generated (see Appendix C). Again, both available literature and insights from conducted interviews were used for this.

Next, the sampling frame was defined and selected. German OEMs are considered the population from which the actual sampling frame can be drawn. The techniques for sampling can largely be divided into probability and non-probability samples (Churchill, 1995). Probability samples are distinguished by the fact that each population element has a known change of being included in the sampling frame, whereas non-probability samples have guarantee of being included. In this study, a non-probability sample is used which involves personal judgement in the selection process and corresponds with cross-sectional research (Zajac & Shortell, 1989; Langerak, 1997).

Within the non-probabilistic sample different techniques are used. First of all, a convenience sample is taken which refers to inclusion of elements in the sampling frame based on accidental circumstances. Secondly, the sampling frame consists of judgement samples that are often referred to as purposive samples. In other words, several elements that are included in the sample are 'hand-picked' because it is expected that they can serve the specified research purpose (Churchill, 1995).

A complete definition of the sampling frame can be achieved best by combining different sources of information (Boyed *et al.,* 1988; Langerak, 1997). For this study a database was built in which elements from the Verband der Deutschen Automobilindustrie (VDA), Arthur D. Little (ADL), and one OEM were included. Multiple sources of data are explicitly taken since this reduces the chance of error (Langerak, 1997).

For module suppliers, the standard industrial codes (SIC) and organisational size were initially defined as selection criteria. However, the use of available classifications of this OEM proved to be more valuable than often applied SIC classification. Still, the organisational size was retained as a refinement criterion in order to ensure the selection of medium to large module suppliers. First tier module suppliers of a reasonable size and usually employ between 1000 and 20.000 full-time equivalents (FTEs). Furthermore, knowledgeable respondents with different functional backgrounds (e.g. production, sales, logistics) were identified to which the questionnaires could be sent.

In the pre-testing phase of the questionnaire, potential respondents were contacted by phone, told of the subject and were asked to participate. After an initial validation, a structured questionnaire was developed containing both direct and indirect questions. The final questionnaire was sent to the respondents by e-mail, and thus provided a relatively low cost per contact.

Before sending the final questionnaire to the respondents, they were personally contacted by phone and were asked to participate. Several other measures were taken to increase the response rate. Not only was the confidentiality of the study pointed-out but also the closing date and the time required to fill-in the questionnaire. In addition, the possibility to receive a summary of the findings of this study was offered as an incentive. The offering of an incentive has been found to positively impact the response rate (Yu & Cooper, 1993). Finally, after the closing date, a 'reminder' e-mail was sent to the non-respondents with the repeated request to participate.

4.6.2 Structure of the questionnaire & pre-testing

The questionnaire used contains both direct and indirect questions and has been developed after an extensive literature review and several interviews with academics and practitioners.

In the first section of the questionnaire, characteristics of the respondent and the module supplier are requested using open and closed questions. In the second section, the research constructs are presented including their scale items. The respondent is asked to indicate the extent to which he/she agrees with the statements made on a 1-dimensional 5-point Likert scale[29], which is generally accepted among researchers (e.g. Gupta & Somers, 1992; Koste, 1999).

The judgement of the statements made in a questionnaire depends on the respondent's point of view. The subjective impression of respondents does not distort a 'good' measurement since there exists a strong correlation between subjective and objective performance measurement (Pearce *et al.*, 1987; Slater & Narver, 1996). Furthermore, the judgement is primarily an assessment by the respondent in comparison to the most important competitor in the market (Slater & Narver, 1996).

Many of the proposed items for a specific flexibility dimension have not been used in previous scale development efforts. Consequently, it was considered necessary to pre-test the proposed items in two phases. In the first phase, a Q-sorted test was performed to analyse the quality of the manufacturing flexibility dimensions. In the Q-sorted test, the aim was to identify those scale items that could be grouped together. The task of the respondents in the Q-sorted test parallels that for the judgement sample in developing a 'Thurstone equal-appearing interval scale'[30] (Churchill, 1995) with the exception that the

[29] 1= entirely disagree, 2=disagree, 3=neutral, 4= agree, 5= entirely agree.

[30] See Thurstone & Chave (1929).

respondents answer each stimulus in terms of their attitude towards it and not in terms of its degree of favourableness.

In the Q-sorted test, the proposed items needed to be matched with the appropriate flexibility dimension. In order to achieve this, the scale items were randomly arranged. This was done in order to prevent any unintended implication of the constructs with a specific item. After the matching process was completed, the results were analysed for the frequency with which each item is correctly associated with its intended flexibility dimension. After the completion of the test, the respondents were asked to convey any difficulties they had in understanding the items. In total, 10 respondents (5 academics, 5 practitioners) completed the Q-sorted test.

In the second phase of the pre-testing, a pilot study was conducted to test the quality of the questionnaire that was to be used in the large-scale data collection. A convenience sample (n=20) of respondents was selected from the sample frame and personally contacted, told of the subject of the study, and were asked to participate. This approach allowed an additional personal explanation and offered the opportunity to prevent missing values (Nijssen, 1992). The questionnaire was completed by a total of 15 respondents, who provided qualitative feedback via notes and comments on the clarity of both the instructions and the proposed scale items.

4.7 Conclusions

In this chapter, the conceptual framework for this study was presented including the research design necessary for validation. This conceptual framework is a translation of the expected relationships between the research constructs as described in chapters 2 and 3. In this conceptual model, several moderating variables were defined that were expected to influence the relationship between modular sourcing and manufacturing flexibility. In addition several quasi-moderating variables were included as well since it is very likely that other variables than modular sourcing affect the level manufacturing flexibility achieved. Finally, based on this conceptual framework, several propositions were offered that need to be explored and validated. It was argued that the use of both exploratory case studies and survey-based research is in alignment with the insights of triangulation and allows the integration of fieldwork and survey methods. Moreover, the application of multiple methods not only increases the accuracy of the study, but also allows the formulation of more conclusive findings if the applied methods lead to similar conclusions. Exploratory research is particularly helpful in breaking down broad problem definitions into smaller, more precise sub-problem statements. The research process for exploratory case studies was described as well as the use of case study protocols. Finally, the ‘construct validity’, ‘internal validity’, ‘external validity’, and ‘reliability’ of this type of research have been discussed. Survey-based research is applied to validate the propositions concerning the main research construct. In order to test these relationships, a multi-item scale needs to be developed. In this study, these scales will be developed using the framework of Churchill (1979) that is widely accepted by researchers. This eight-step framework was discussed, including: domain specification, item development, the sampling frame, data collection, structure of the questionnaire, and the pre-testing in two phases.

5 Exploratory case study results

While product demands placed upon firms are changing in dramatic ways – products life cycles are shorter, demand for product choice is swelling, pressures for globalisation and technological innovation are overwhelming – the firm's need to respond to change with stable and long-term, yet flexible and responsive, process capabilities is greater than ever before.

(Boynton and Victor, 1991, p. 53)

5.1 Introduction

In this chapter the results of four exploratory case studies are presented. These case studies help in answering the secondary research questions (*What moderating and quasi-moderating variables can be identified that influence the relationship between modular sourcing and manufacturing flexibility?)* and (*What dimensions of manufacturing flexibility can be identified and how can they be structured?)*. The exploratory case studies are used to explore the conceptual framework as proposed in chapter 4. Because of the confidentiality of the conducted case studies, only a limited amount of organisational specifics can be described[31].

In paragraph 5.2 the suppliers are briefly introduced followed by the analysis of the relationship between modular sourcing and manufacturing flexibility (paragraph 5.3). Next, the following moderating variables are discussed that influence the relationship between modular sourcing and manufacturing flexibility: the extent of complexity (paragraph 5.4), the extent of vertical integration (paragraph 5.5), process and product know-how (paragraph 5.6), and the governance choices (paragraph 5.7). In paragraph 5.8 the implications of process responsibility on the relationship between the two main research constructs are described. Finally, paragraph 5.9 summarises the most important findings of the exploratory case studies.

[31] Information on organisational size, product range, competitive position, countries of operation and financial data will not be discussed since this will indirectly reveal the OEM discussed.

5.2 Supplier characteristics

This paragraph provides an overview the suppliers observed in the case studies based on the classification as developed in chapter 2. For every case study a co-supplier, main supplier, and module supplier were selected for further analysis.

Table 5-1: Environment and characteristics of suppliers for Alphacar

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
	GENERAL		
Type of product	n.a.	Engine starters	Axes for steering module
Home country	n.a.	Germany	Germany
Proximity to OEM	n.a.	Within 20 km	Within 25 km
Key competitiveness	n.a.	Price of product, product quality consistency	Outstanding performance in quality, logistics and cost optimisation.
	TECHNOLOGY		
Competence	n.a.	Product know-how	Process and product know-how
Technological lifecycle	n.a.	Existing technology / new technology	New technology / new technology
Development of base technology	n.a.	No	Yes, at own risk
Investments	n.a.	++	+++
Problem solving ability	n.a.	+	+++
Product development	n.a.	Yes	Yes
Logistical capabilities	n.a.	++	+++
JIT / JIT variations	n.a.	JIT	JIS
Identification of products	n.a.	Scanning on the box level	Scanning on module level
	PROCESS		
Process technology	n.a.	Assembly	Assembly
Process integration / synchronisation	n.a.	+++	+++
	PRODUCT		
Type of product	n.a.	Component	Module
Value of component	n.a.	+	+++
Functional changeability	n.a.	+	+++
Process integration	n.a.	+	+++
	MARKET		
Competitive scope	n.a.	Oligopoly	Oligopoly
Position in hierarchy	n.a.	Concentration	Concentration
Primary client(s)	n.a.	First tier	First tier
Vertical cooperation	n.a.	OEM	OEM

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
MARKET (CONTINUED)			
Intensity of cooperation	n.a.	Production and development	Production and development
Single sourcing / multiple sourcing	n.a.	+++	+++
Mutual dependence	n.a.	Single sourcing	Single sourcing
Manufacturing strategy	n.a.	+	+++
Worldwide presence	n.a.	Global efficiency	Global efficiency
International production network	n.a.	Yes	Yes

Table 5-1 summarises the findings of the selected suppliers for Alphacar. Alphacar not only works extensively with several module suppliers, it is also a specialist for ceramic brake systems that are sold to other OEMs. In addition to this competence, Alphacar designs other components and 'kaizen'-based processes for these OEMs. Alphacar uses a limited number of module suppliers and only externalises the development and production of products in which no competitive advantage can be achieved. Internally, Alphacar only distinguish two supplier types that correspond to the main and module supplier characteristics as described in paragraph 2.5.2. Therefore, no co-suppliers are observed in this case study.

The selected suppliers for Alphacar are large first tier players that supply to many other OEMs as well. The observed main supplier has over thirty years experience in the development and production of different kinds of power-train components. This specialist provides a broad range of technologies for different applications such as gasoline engine technology for mixture preparation, combustion and exhaust-after-treatment systems. The requirements for these components are not restricted to performance and reliability but include compliance with increasingly strict environmental legislation as well. Furthermore, this specialist closely cooperates with catalytic converter suppliers in order to develop and produce high quality innovative products. The selected module supplier is one of the world largest automotive suppliers and operates in 16 countries from more than 120 locations. With the use of a global supply network this supplier is able to develop and produce customised solutions for the chassis, body and power train areas for almost all OEMs. For this study, the chassis business unit is observed that develops and supplies complete ready-to-install axles and air suspension systems. Furthermore, this module supplier produces cabin suspension systems for leading European truck manufacturers as well. This supplier has been delivering complete front- and rear axles for several Alphacar model lines in the past years and has received several supplier awards. Overall, Alphacar is very satisfied with this supplier that performs well in areas such as innovation, quality, and logistics (JIS and JIT).

Table 5-2: Environment and characteristics of suppliers for Betacar

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
		GENERAL	
Type of product	Intake manifolds, fuel rails, centre consoles	Carbon, aluminium, leather, precious wood finishes	Instrument panel / cockpit modules
Home country	Germany	Germany	France
Proximity to OEM	Within 100 km	Within 200 km	Within 50 km
Key competitiveness	Process solutions, process know-how, product quality, competitive price	Material and processing know-how, product quality	Innovative products, process and product know-how, excellent sub-supplier management
		TECHNOLOGY	
Competence	Process know-how	Product know-how	Process and product know-how
Technological lifecycle	Existing technology	Existing technology / new technology	New technology / new technology
Development of base technology	No	No	Yes, at own risk
Investments	+	+++	+++
Problem solving ability	+	++	+++
Product development	Yes	Yes	Yes
Logistical capabilities	++	++	+++
JIT / JIT variations	JIT	JIT	JIS
Identification of products	Scanning on the box level	Scanning on the box level	Scanning on module level
		PROCESS	
Process technology	Simple assembly	Assembly	Assembly
Process integration / synchronisation	++	+++	+++
		PRODUCT	
Type of product	Component	Component	Module
Value of component	++	++	+++
Functional changeability	++	++	+++
Process integration	++	++	+++
		MARKET	
Competitive scope	Oligopoly	Oligopoly	Oligopoly
Position in hierarchy	Diversification	Concentration	Concentration
Primary client(s)	OEM	OEM	OEM
Vertical cooperation	Production	Production and development	Production and development

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
MARKET (CONTINUED)			
Intensity of cooperation	+	++	+++
Single sourcing / multiple sourcing	Multiple sourcing	Single sourcing	Single sourcing
Mutual dependence	+	++	+++
Manufacturing strategy	Global efficiency	Global efficiency	Global efficiency
Worldwide presence	Yes	Yes	Yes
International production network	Yes	Yes	Yes

Table 5-2 summarises the findings of the selected suppliers for Betacar. The selected suppliers for Betacar are renowned first tier suppliers in the automotive industry as well. The observed co-supplier primarily offers thermoplastic components such as: intake manifolds, fuel rails and centre consoles. Unlike any other material, thermoplastics help to lower part weight and costs while increasing overall functionality of the components. The main supplier offers vehicle finishes (e.g. leader steering wheel, chrome handles, wooden dashboard parts) and possesses a high level of product and process know-how. This know-how is highly specific since the shaping of different types of woods and carbon is difficult and therefore not easy to duplicate. Both the co- and main supplier have worldwide manufacturing facilities and supply to other OEMs and suppliers as well. The observed module supplier develops and produces a range of complex modules such as, seats, cockpits, doors, and front-ends. Depending on the vehicle model, these modules account for up to 15% of the vehicle value. This module supplier has over 150 production and development units around the world and operations in 27 countries. Using this global production and development network, this supplier serves almost all OEMs on all continents. Finally, logistical accuracy is a key competitive advantage of this supplier, who is able to supply products within 250 minutes (calculated as the time between call-off and delivery at the assembly line) to any OEM plant.

Table 5-3: Environment and characteristics of suppliers for Deltacar

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
GENERAL			
Type of product	Plastic components for tanks, water/glycol, hot oil	n.a.	Instrument panel
Home country	Germany	n.a.	Germany
Proximity to OEM	Within 100 km	n.a.	On the premises

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
GENERAL (CONTINUED)			
Key competitiveness	Process solutions, process know-how, product quality, competitive price	n.a.	Product quality, process and product know-how, innovative products
TECHNOLOGY			
Competence	Process know-how	n.a.	Process and product know-how
Technological lifecycle	Existing technology	n.a.	New technology / new technology
Development of base technology	No	n.a.	Yes, at own risk
Investments	+	n.a.	+++
Problem solving ability	+	n.a.	+++
Product development	Yes	n.a.	Yes
Logistical capabilities	++	n.a.	+++
JIT / JIT variations	JIT	n.a.	JIS
Identification of products	Scanning on the box level	n.a.	Scanning on module level
PROCESS			
Process technology	Simple assembly	n.a.	Assembly
Process integration / synchronisation	++	n.a.	+++
PRODUCT			
Type of product	Component	n.a.	Module
Value of component	++	n.a.	+++
Functional changeability	++	n.a.	+++
Process integration	++	n.a.	+++
MARKET			
Competitive scope	Oligopoly	n.a.	Oligopoly
Position in hierarchy	Diversification	n.a.	Concentration
Primary client(s)	First and second tier	n.a.	First tier
Vertical cooperation	OEM and other first tier suppliers	n.a.	OEM
Intensity of cooperation	+	n.a.	+++
Single sourcing / multiple sourcing	Multiple sourcing	n.a.	Single sourcing
Mutual dependence	+	n.a.	+++
Manufacturing strategy	Local efficiency	n.a.	Global efficiency
Worldwide presence	Yes	n.a.	Yes
International production network	Yes	n.a.	Yes

Table 5-3 summarises the findings of the selected suppliers for Deltacar. In the observed plant, Deltacar only distinguishes two suppliers' types that correspond to the main- and module supplier characteristics as described in paragraph 2.5.2. Therefore, no main supplier is observed in this case study. The selected co-supplier offers different types of plastic components such as tanks for water, glycol, or hot oil. These components are often subjected to extreme mechanical, thermal or chemical stress and are designed for rapid assembly and easy maintenance. This main supplier is valued for its competence in processing of materials and is able to deliver its products rapidly to its customers all over the world. The selected module supplier is one of nine module suppliers who are physically integrated in the Deltacar production facility. This supplier offers a wide range of products varying from highly accurate instrument panels to sensor systems for fuel measurement, traction systems, and control units. The module supplier has over 120 research and production units worldwide and is able to offer many different solutions to its customers. Deltacar has a long-time outstanding relationship with this module supplier that has been awarded with several quality prizes.

Table 5-4: Environment and characteristics of suppliers for Etacar

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
GENERAL			
Type of product	Dynamo / starter	Airbags, seatbelt and corresponding sensors	Front-end including lights
Home country	Germany	Germany	France
Proximity to OEM	Within 50 km	Within 50 km	On the premises
Key competitiveness	Product quality, competitive price	Material and processing know-how, product quality, and control	Innovative products, process and product know-how
TECHNOLOGY			
Competence	Process know-how	Product know-how	Process and product know-how
Technological lifecycle	Existing technology	Existing technology / new technology	New technology / new technology
Development of base technology	No	No	Yes, at own risk
Investments	+	+++	+++
Problem solving ability	+	++	+++
Product development	Yes	Yes	Yes
Logistical capabilities	++	++	+++
JIT / JIT variations	JIT	JIT	JIS
Identification of products	Scanning on the box level	Scanning on the box level	Scanning on module level
PROCESS			
Process technology	Simple assembly	Assembly	Assembly
Process integration / synchronisation	++	+++	+++

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
	PRODUCT		
Type of product	Component	Component	Module
Value of component	+	+++	+++
Functional changeability	+	++	+++
Process integration	+	++	+++
	MARKET		
Competitive scope	Oligopoly	Oligopoly	Oligopoly
Position in hierarchy	Diversification	Concentration	Concentration
Primary client(s)	First and second tier	First tier	First tier
Vertical cooperation	OEM and other first tier suppliers	OEM	OEM
Intensity of cooperation	Production	Production and development	Production and development
Single sourcing / multiple sourcing	+	+	+++
Mutual dependence	Multiple sourcing	Single sourcing	Single sourcing
Manufacturing strategy	+	+	+++
Worldwide presence	Global efficiency	Global efficiency	Global efficiency
International production network	Yes	Yes	Yes

Table 5-4 summarises the findings of the selected suppliers for Etacar. The selected co-supplier offers a variety of high quality components (e.g. powertrains, starters, and dynamos) at competitive prices. This co-supplier invests about 11% of the company turnover in process developments in order to stay ahead of competition. This co-supplier has contracts with almost all OEMs and produces in 25 locations in Europe, North America, and Asia. The observed main supplier offers products that enhance individual passenger comfort and safety such as airbags and seatbelts including sensor systems. This supplier has an excellent long-term relationship with Etacar and is able to supply its solutions and products to many Etacar production locations on different continents. The selected module supplier is one of seven module suppliers who are physically integrated in the vehicle assembly facility of Etacar. This supplier delivers the complete front-end module including the headlight system of the vehicle produced in this plant. This German-based module supplier has over 130 production and research locations worldwide and has received several quality awards from its global customer base.

Observing the supplier characteristics in this paragraph it can be concluded that the application of modular sourcing has tremendously increased the requirements on suppliers. Table 5-5 summarises the most important supplier requirements that have come up in the interviews with both OEMs and suppliers.

Table 5-5: Increased supplier requirements

• Increased flexibility • Integration of the latest technological developments in products • Availability of development capacity • Creativity, innovation possibilities and own initiatives • Simultaneous engineering possibilities	• High level of process security • Technical requirements (CAD, CAM, EDI) • JIT and JIS supply • Worldwide presence • Enhanced sub-supplier management • Zero failure tolerance

The increasing supplier requirements often entail major investments in process improvements, R&D, and quality control. Furthermore, these requirements pose tremendous stress on suppliers that need to acquire specialised capabilities and competencies in a very short time. For instance, in the discussion with the Deltacar and Etacar management it became clear that their initial start-up difficulties could largely be traced back to the challenges suppliers were facing in becoming a module supplier. As a manager of Deltacar illustrated:

> *"…in the new plant the suppliers were willing to take responsibility, yet they lacked the experience. We needed to invest al lot of resources in order for them to become true module suppliers".*

It appeared that the selected suppliers had difficulties to comply with the increased supplier requirements. Before the synergies of a modular sourcing relationship could be reaped, time and resources of both parties needed to be invested. A similar experience was made in the observed Etacar plant and forced a postponement the market introduction of the new vehicle model. Deltacar and Etacar considered a pro-active role of the OEM in supplier management is crucial to avoid such difficulties in the future. As one manager of Etacar illustrated:

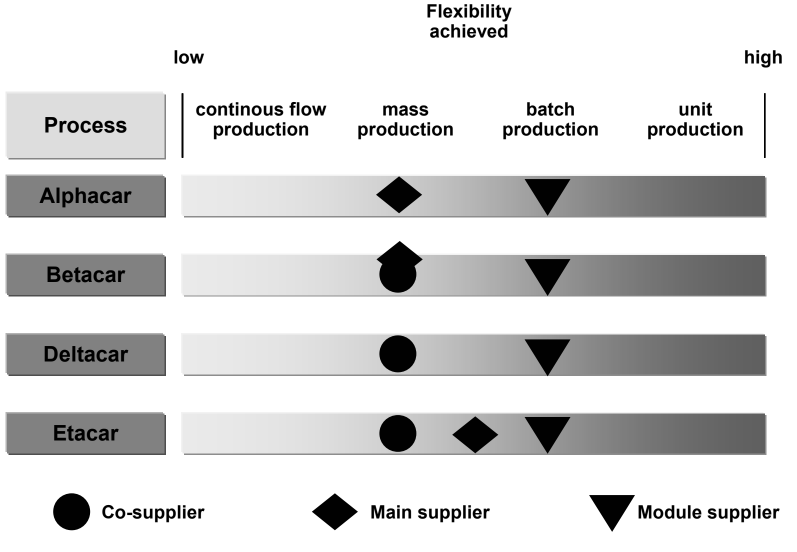
> *"... instead of waiting for the supplier to knock on our door and ask for help, we now visit our module suppliers and see for our selves how they are doing. In such personal visits one can better judge what difficulties may be expected."*

5.3 Flexibility dimensions

5.3.1 Process flexibility

In the interviews, the proposed dimensions were considered to fully comprise the domain of the manufacturing flexibility construct. Furthermore, a high extent of correlation between the performance of the OEM's and supplier's manufacturing system was confirmed. A summary of the extent of process flexibility achieved by the suppliers in the case studies is depicted in figure 5-1.

Figure 5-1: Extent of process flexibility



As can be derived from figure 5-1, the co- and main suppliers primarily apply mass production processes in order to increase efficiency and keep the production co sts as low as possible. The mass production process choices are typically restricted by many regulations with impersonal control of the process. In other words, the extent of flexibility achieved is inhibited by technological constraints. On the other hand, module suppliers primarily apply (large size) batch production that entails a higher extent of flexibility. In this process choice each production-lot passes through one stage of the process before entering the next. This means that the production capacity at each stage of production is used to meet the different requirements of orders.

The OEMs observed apply a combination of mass production and batch production oriented processes. For some low-volume exclusive vehicle brands (e.g. Bugatti, Maybach, Rolls Royce) these OEMs apply unit production. Depending on the process stages different processes are chosen. For instance, the pressing of body parts and coating is done in batches in order to minimise the set-up times and costs. On the other hand final assembly activities are organised in mass production processes. It should be noted that in batch production, minimal buffers between process steps are necessary to flexibly respond to changes in the production sequence. These in-between process steps are referred to as ‘process decoupling point(s)’.

Among the interviewed managers is was generally argued that the mass production and batch production process choices entail short processing times and a high level of plant utilisation. In addition, it was confirmed that even though the performance of the mass production system in terms of output is the highest, the extent of freedom to react to sudden changes in demand is lower than in batch processes. It should be noted that the inclusion of continuous flow processes in this scale was considered relevant for grasping the entire range of process flexibility, yet can primarily be found in other industries (e.g. chemical and oil industry).

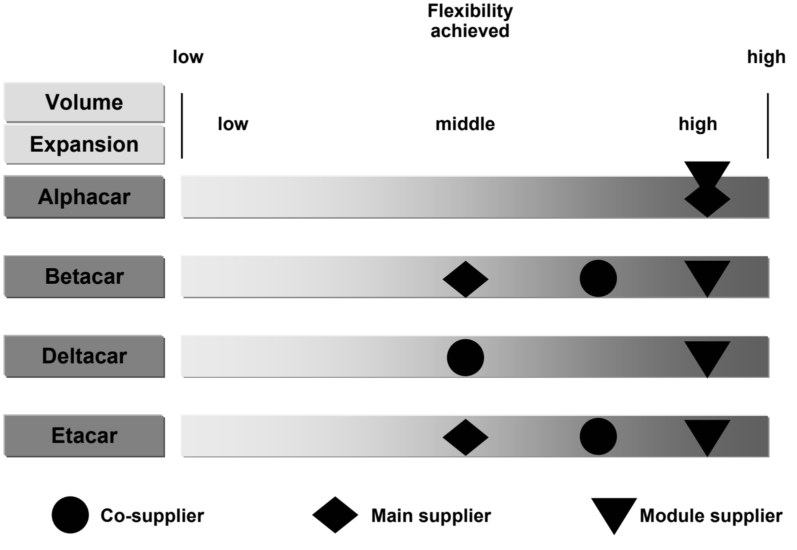
An important step in increasing the mobility, uniformity, and stability of production processes is an accurate production planning. The objective is to provide as much stability in the mid-term and short-term as possible. Practices among the observed OEMs vary somewhat, but two are quite common. First, when initiating new processes there is an absolute insistence on process stability. Each new process must be thoroughly tested and brought under tight statistical process control before being released to the shop floor. This does not imply that there is no room for subsequent process improvement. However, no plant should be dealing with process ‘debugging’ during process runs. Second, production schedule freeze points should be set as far in advance as possible when new processes are implemented. After enough experience has been made, freeze points should be postponed again to increase flexibility. For example, Betacar has combined an accurate forecast, which is updated daily for its suppliers, with a postponed freezing point to increase flexibility. Four days before final assembly, the production sequence is frozen, after which the body frame assembly can be planned. This represents the first decoupling point in which optimal batch sizes can be planned. After the body frame assembly, the order sequence is decoupled again in order to determine the optimal batch sizes for the coating process. This second decoupling point is followed by a third one shortly before final assembly. Based on these arguments, the following proposition is offered:

Proposition 1a: **Modular sourcing has a positive effect on the level of process flexibility achieved.**

5.3.2 Volume & expansion flexibility

A summary of the extent of volume and expansion flexibility achieved by the suppliers in the case studies is depicted in figure 5-2.

Figure 5-2: Extent of volume and expansion flexibility



As can be derived from figure 5-2, module suppliers are in most cases considered more flexible with respect to volume and expansions than co- and main suppliers. In the Alphacar case the main and module supplier was considered equally flexible since their volumes and expansions were not considered constraining factors. Volume and expansion flexibility were considered as not only important in supplier valuation programs but were also deemed as highly interrelated. A Betacar manager stated:

> *"… if the increasing volume changes cannot be met in the short run, additional production capacity has to be build".*

Volume flexibility allows organisations to respond to both decreases and increases in the aggregate demand at a given configuration. Furthermore, the short-term volume flexibility was considered vital to the mobility, uniformity, and stability of manufacturing systems. The interviewed managers argued that an accurate production program forecast increases the volume flexibility since changes in demand can be anticipated.

Volume flexibility highly depends on factors such as: number and heterogeneity of product offerings, process choice, machine layout, and physical proximity of suppliers. For instance, the observed main supplier for Betacar is less flexible in comparison because of the complex and long processing times of the wooden finishes. In addition, this supplier in turn depends on suppliers that source different types of wood from remote locations (e.g. South-America). Furthermore, the main supplier is remotely located (approximately 180 km) from the observed plant and cannot supply the goods in short notice. In order to increase the stability for these components larger volumes are supplied to Betacar that usually last for 2-4 days of production. However, this increases the stock costs, and requires additional handling.

Among the interviewed managers it was generally understood that expansion flexibility has important implications for the competitive position of an organisation. If an organisation is able to consider long-term demand changes (e.g. because of changes in the business environment) in the expansions that are made, the competitive position can be enhanced. Thus, long-term expansion flexibility is related to the strategic planning for which short-term volume fluctuations are indicators. For instance, Betacar observed an unexpected and continuous increase in demand for model A. For this reason it was decided to expand production capacity in the proximity of the original plant. The new plant was constructed in only 18 months and in turn increased the short-term volume flexibility since production volumes could be shifted between the two plants.

An effective use of the production network not only enables volumes to be swapped between the plants but also reduces the need for equipment. For instance, Betacar uses three plants for the production of vehicle model B. Following the construction of the body in white and the coating process in ‘plant 1’, final assembly of this model takes place at ‘plant 2’, using parts and components supplied by ‘plant 3’. This production network relies heavily on the logistical accuracy in which JIT, JIS, and synchronic manufacturing needs to be controlled across plants. Based on these arguments, the following propositions are offered:

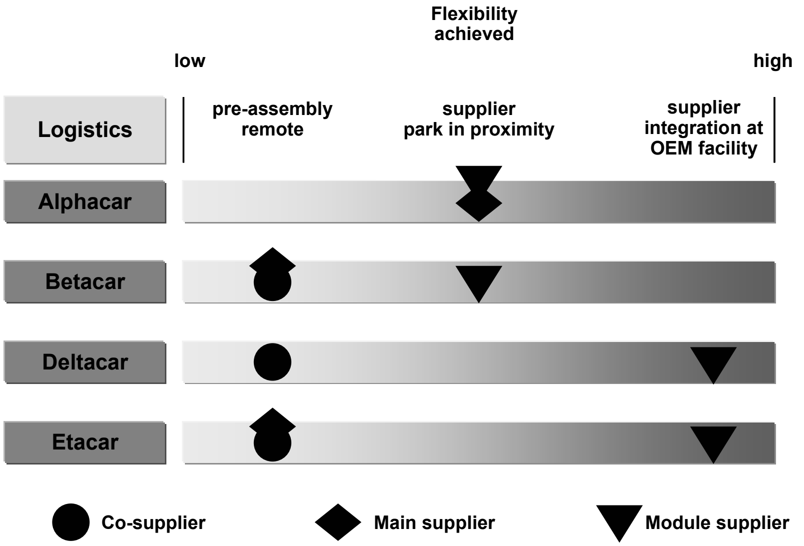
Proposition 1b: Modular sourcing has a positive effect on the level of volume flexibility achieved.

Proposition 1c: Modular sourcing has a positive effect on the level of expansion flexibility achieved.

5.3.3 Logistical flexibility

A summary of the extent of logistical flexibility achieved by the suppliers in the case studies is depicted in figure 5-3.

Figure 5-3: Extent of logistical flexibility



Observing figure 5-3, it can be concluded that module suppliers are in most cases considered more flexible than co- and main suppliers. The latter two mentioned suppliers deliver components JIT, whereas modules are supplied JIS. Among the interviewed managers I was generally understood that the physical proximity of the supplier to the OEM increases the stability of both JIT and JIS supply.

In the Alphacar case the main and module supplier were considered as equally flexible. The former mentioned supplier uses a JIT delivery, whereas the modules are supplied JIS. Both suppliers are located in the vicinity (within 20 km) of the Alphacar. Since both suppliers have a 97% delivery accuracy, it was argued that the added value of integrating these suppliers in the production facility is relatively low.

Even though the co- and main suppliers for Betacar are more remotely located (100-200 km), the flexibility achieved was considered sufficient as well. The observed module supplier is located in the proximity (within 50 km) of the Betacar plant and supplies the goods JIS. However, the observed Betacar plant itself has become an inhibiting factor for the logistical flexibility. The plant is situated in a relatively dense populated area, which limits the expansion possibilities. Because the production capacity has been growing over the years, the central stocking facility was relocated about 20 km away from the plant. The majority of the components are stored at this location and are transported to the plant by shuttle service. This logistical 'hub' requires highly efficient processes and is considered extremely crucial to the flexibility of the manufacturing system achieved.

In the observed Deltacar and Etacar plants, the module suppliers have been integrated into the assembly facility. Both plants were designed to optimise the inbound and outbound flow of goods and resulted in many docking stations along the assembly line. An Etacar manager stated that the proximity to the assembly line reduces transportation costs by 30-40%, handling costs by 15%, and assembly time by 5-10% compared to a traditional design. Even though the integration of suppliers on the OEMs premise ensures an optimal logistical layout, it also increases the complexity for module suppliers and logistical service provider. In other words, the range-number and heterogeneity for these parties is increased since multiple docking stations have to be visited. The interviewed managers of Deltacar and Etacar argued that good experiences were made with physically integrated suppliers and positively affected the manufacturing flexibility. Based on these arguments, the following propositions are offered:

Proposition 1d: Modular sourcing has a positive effect on the level of logistical flexibility achieved.

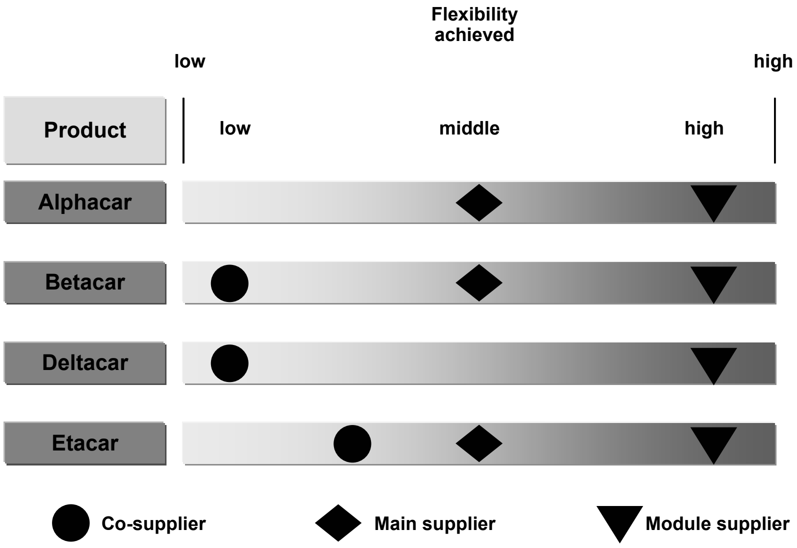
5.3.4 Product flexibility

A summary of the extent of product flexibility achieved by the suppliers in the case studies is depicted in figure 5-4.

As can be derived from figure 5-4, the extent of product flexibility achieved is the highest for module suppliers in all cases. Co-suppliers are generally considered as less flexible concerning products, which can be explained by their focus on process rather than product know-how (see paragraph 5.6). It should be noted that the ability to make functional changes often does not apply to co-suppliers, since these suppliers merely produce components based on the technical drawings of the OEM.

Among the interviewed managers it was uniformly recognised that the complexity of vehicles has been increasing. Not only the number of product offerings has been increasing but also the variety, which is largely caused by increasing technical content (e.g. engine control systems, electronic stability programs, infotainment).

Figure 5-4: Extent of product flexibility



Furthermore, the use of modular product architectures and platforms were considered important in reducing product complexity. This combination allowed the observed OEMs to reduce the development lead-time by approximately 15% as compared to five years ago. In addition, this combination enabled the OEMs to increase the variety of product offerings without tremendously increasing costs or changing the performance of the manufacturing system (in terms of mobility, and uniformity). The ability to provide customised products at acceptable costs allows higher retail prices and enables an OEM to enter niche markets that would otherwise be unprofitable. Based on these arguments, the following proposition is offered:

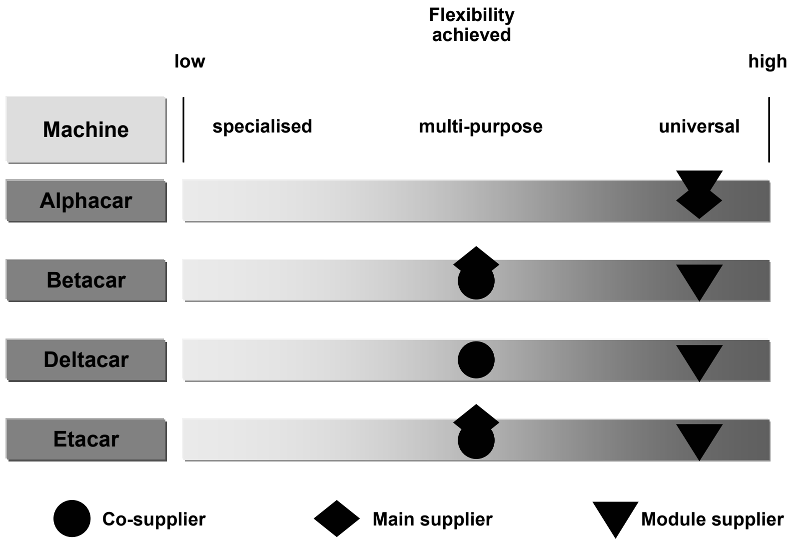
Proposition 1e: Modular sourcing has a positive effect on the level of product flexibility achieved.

5.3.5 Machine flexibility

A summary of the extent of machine flexibility achieved by the suppliers in the case studies is depicted in figure 5-5.

Observing figure 5-5 it can be concluded that module suppliers in most cases are observed as more flexible compared to other supplier types. Co- and main suppliers primarily use multi-purpose machines for the production of components. These machines have comparatively long set-up times and are able to perform a limited number of specialised operations. In other words, the range, number and heterogeneity of the machines used is comparatively less high than machines used by module suppliers.

Figure 5-5: Extent of machine flexibility



Module suppliers heavily invest in machine technology in order to perform highly specialised tasks and at the same time can be re-programmed easily. The use of cost intensive universal machines allows these suppliers to generate scale advantages since they are able to perform similar operations for different clients. The ability to change specific operations quickly without creating massive upheavals in the manufacturing system indicates a high level of mobility and uniformity of the manufacturing system. For instance, a specific module supplier produces the vehicle body frames for a specific Etacar model. A typical machine of this supplier fits together over 400 parts and executes over a thousand welding operations. These machines can be re-programmed relatively easily in order perform similar operations for different body frames. Based on these arguments, the following proposition is offered:

Proposition 1f: Modular sourcing has a positive effect on the level of machine flexibility achieved.

In the discussion it became clear that investments in universal machines are not only driven by the application of modular sourcing. Often technological developments are implemented to improve the flexibility of the manufacturing system. These developments can include, a wider range of products that can be produced on the same machine, a reduction of set-up and retooling times, and increased throughput time.

An Etacar manager stated that these technological developments are enhanced by simultaneous developments in information technology and challenge the long held belief that higher levels of automation are less flexible in nature. Therefore, the following proposition is offered:

Proposition 3a: Technological developments positively influence manufacturing flexibility.

Furthermore, among the interviewed managers it was argued that learnings from internal processes play an important role in the improvement of manufacturing flexibility. These learnings are not necessarily related to modular sourcing and often are based on internal process improvements. Learning curve advantages observe the relationship between the average production costs and the total amount of volume produced. The average cost per vehicle decrease as the total amount of vehicles is increased. A manager of Etacar illustrated:

> *"Especially in the start-up phase we needed to improve and fine-tune operational processes".*

Etacar quickly moved down the learning curve and was able to reach the calculated optimal cost levels. Therefore, the following proposition is offered:

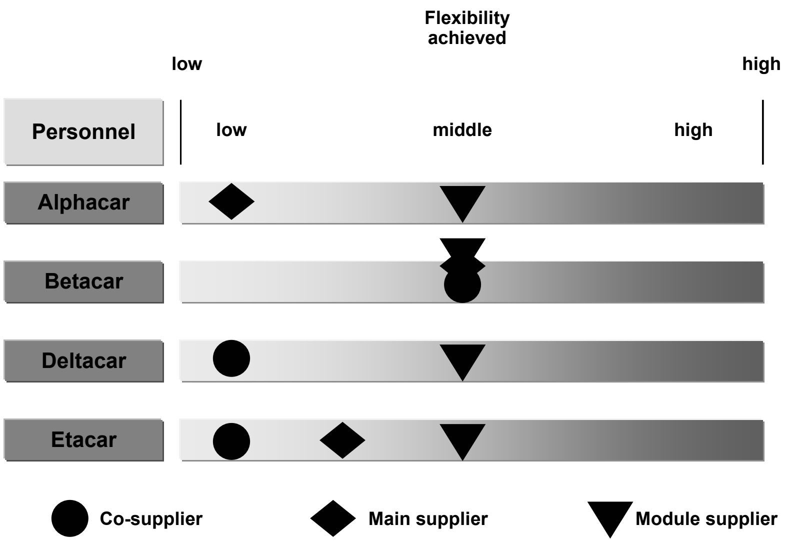
Proposition 3b: Learning made positively influence manufacturing flexibility.

5.3.6 Personnel flexibility

A summary of the extent of personnel flexibility achieved by the suppliers in the case studies is depicted in figure 5-6.

Observing figure 5-6 it can be concluded that module suppliers achieve at least equal or higher levels of personnel flexibility as compared to co- and main suppliers. In the Betacar case the functional and numerical personnel flexibility of the co-, main, and module supplier were not considered inhibiting factors. Therefore, it was argued that these three supplier types achieve the same level of personnel flexibility.

Figure 5-6: Extent of personnel flexibility



Among the interviewed managers it was argued that personnel flexibility primarily influences the extent of process flexibility achieved. Increasing personnel flexibility by training, education, and job rotation enlarges the mobility of personnel. Moreover, personnel that can perform a variety of tasks are able to remain productive when tasks are swapped and thus improve the uniformity of the manufacturing system. Furthermore, improved functional flexibility positively influences motivation. A motivated employee is more consistent in the performance outcomes and even may increase the number and variety (range number and heterogeneity) of tasks he/she can perform, for personal satisfaction. Team structures are often used to enhance the functional flexibility of personnel. However, a team can be too large, which can have negative effects as well (e.g. loss team spirit). The interviewed managers argued that, depending on the environment, the optimal average team size is between 20 and 25 people. Furthermore, the team leader job was considered crucial, and thus demands careful attention in designing teams. Overall, team leaders are most effective when they are fully 'plugged' into the team rather than be positioned above it. This implies that each team leader needs to know every team member's job, be able to competently carry it out and teach it, and be well connected with the leaders of adjacent teams.

Numerical flexibility was considered to enhance personnel flexibility as well. However, this was deemed of minor importance since it cannot be influenced on a plant level. Work time regulations are negotiated with labour unions that have, depending on the country observed, different levels of influence. Especially in Germany, labour unions have build-up many securities and have a very strong negotiating position. Within the limits of the union agreements, OEMs try to enhance the flexibility as much as possible. For instance, the proximity of several Betacar plants enable a more optimal use of capacities since manpower can be exchanged between the plants. Based on these arguments, the following proposition is offered:

Proposition 1g: Modular sourcing has a positive effect on the level of personnel flexibility achieved.

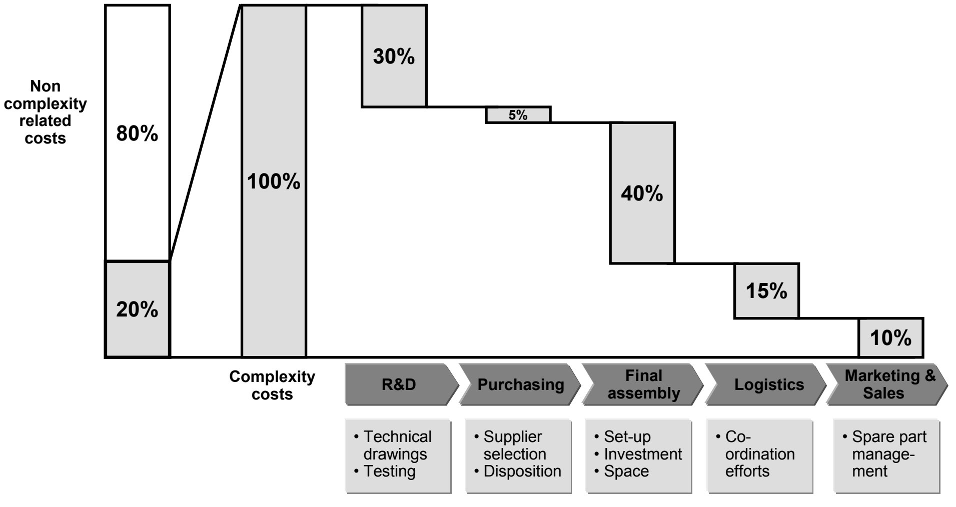
5.4 Extent of complexity

In this paragraph the aim to reduce extent of complexity is analysed, which is considered to influence the relationship between modular sourcing and manufacturing flexibility as a quasi-moderating variable.

All four OEMs increase the number vehicle models offered and improve the quality of their service offerings as a basis for differentiation in the mature industry. Furthermore, the level of competition is increasing since all four OEMs operate in the global market place. At the same time the observed German OEMs face an increased level of competition in their domestic marketplace. For example, even though Deltacar has secured its market position in Germany with a mid-size vehicle model, it faces tough competition in this segment from French OEMs. The latter mentioned OEMs introduce similar high quality vehicles at lower costs in order to gain a larger share of the market. Because of the strong brand, Deltacar is able to maintain their market share.

In the effort to expand and increase profitability, the observed OEMs need to increase their range of product offerings. As a result, the complexity of the product program is increased since not only the number of vehicle models is increased but also the variety per vehicle. In following such a differentiation strategy the investments have to be minimised to be able to produce a vehicle at acceptable cost. This is necessary since these investments can only be amortised over a relatively small (niche) sales volume. Therefore, OEMs are (from a cost perspective) forced to outsource a large part of non-strategic components and modules in order to reduce complexity and related costs. However, it should be noted that the complexity related costs are merely transferred to the module supplier. Information on how the complexity costs have been changing over time was hard to obtain. First of all, the quantification of the level of complexity was difficult since many complexity drivers are highly interrelated. Secondly, it became clear that controlling departments do not have process cost calculations that observe complexity cost and were only able to roughly indicate their height. Based on the available information and research conducted by Rommel *et al.* (1993) an overview of the complexity costs was made for a typical Etacar vehicle (see figure 5-7).

Figure 5-7: Complexity costs



An estimated 20% of the total costs of a new Etacar vehicle are related to complexity. These complexity costs can be split-up according to several generic processes as depicted in figure 5-7. The Etacar management stated that the application of modular sourcing primarily reduces the height of their complexity cost for R&D and final assembly related processes. Furthermore, it was confirmed that the effects of the reduced complexity do not instantly become apparent. The explanation of a time-delay between measure and effect seemed plausible to the managers. In addition, it was argued that the disadvantages of this time-delay are partly reduced for the OEM when modular sourcing is applied. Since the constant costs of the OEM are swapped against variable costs of purchasing modules, the negative effects of a time delay are shifted towards the module supplier.

These findings confirm the theoretical assumptions of Boutellier *et al.* (1997) and explain why the interviewed managers were only able to provide indirect evidence of reduced complexity. The indirect evidence included higher levels of productivity and the ability to produce multiple models on one assembly line compared to ten years ago. However, this evidence is partly blurred since higher productivity levels of the manufacturing system are likely to be influenced by technical developments and learning effects as well (see paragraph 5.3.5).

It should be noted that OEMs are often not convinced that they have developed the appropriate methodology that allows them to fully calculate to total costs of external and internal supply. Furthermore, in the interviews it became clear that decisions to outsource are even made if the immediate cost calculations do not clearly show economic gains. Based on these arguments, the following propositions are offered:

Proposition 2a: Complexity reduction of the OEM positively influences the relationship between modular sourcing and manufacturing flexibility.

In the discussion, the use of contract manufacturers was considered important in reducing the complexity as well. A contract manufacturer is an independent organisation that produces entire vehicles on behalf of the OEM. In table 5-6 an overview of the contract manufacturing characteristics for the observed OEMs is given.

Table 5-6: Contract manufacturing characteristics

	ALPHACAR	BETACAR	DELTACAR	ETACAR
Vehicle type assembled by contract manufacturer	Convertible	Sports utility vehicle (SUV)	Convertible	Convertible
Assembly of identical / similar vehicle types by the OEMs themselves	Identical	Neither identical nor similar model (SUV is only produced by the contract manufacturer)	Similar	Similar
Dependence on contract manufacturer	Medium	High	Medium	Medium

Alphacar has a long-term relationship with a contract manufacturer in Finland for the assembly of a specific convertible vehicle model. This constellation enables Alphacar to ‘extend’ their own assembly line (which produces the identical model) and increase the level of volume flexibility without high investments. The

Alphacar management argued that final assembly is a core activity and that entirely outsourcing assembly activities to third parties is not a strategic aim.

A contract manufacturer in Austria assembles a sport utility vehicle (SUV) on behalf of Betacar. Betacar argued that the transfer of the level complexity and the reduced need for investments are the primary reason to apply contract manufacturing. In contrast to Alphacar, Betacar does not assemble this SUV and entirely depends on the contract manufacturer. The described situation may be questionable from the viewpoint of core competencies and dependability, yet clearly a short-term cost focus dominated this decision. Betacar argued that the SUV could not be produced in the existing plants because of capacity restrictions. On the other hand, the relatively low SUV production volume did not justify the investments for a new plant. In addition, a Betacar manager stated:

> *"… even if it had been decided to build additional production capacity, the time-to-market was considered very critical".*

Thus, several factors favoured the use of contract manufacturing for the SUV model. The Betacar management stated that this setting is exceptional and is not the leeway for large volume models. Like Alphacar, Betacar is currently constructing a new plant in Germany, which indicates that final assembly activities for large volume models are considered core operations and will not outsourced.

Both Deltacar and Etacar engage in contract manufacturing relationships for similar reasons. The contract manufacturers of these OEMs produce a convertible version of a large volume model. The outsourcing of final assembly activities for these niche models was considered necessary since they could otherwise not be produced economically.

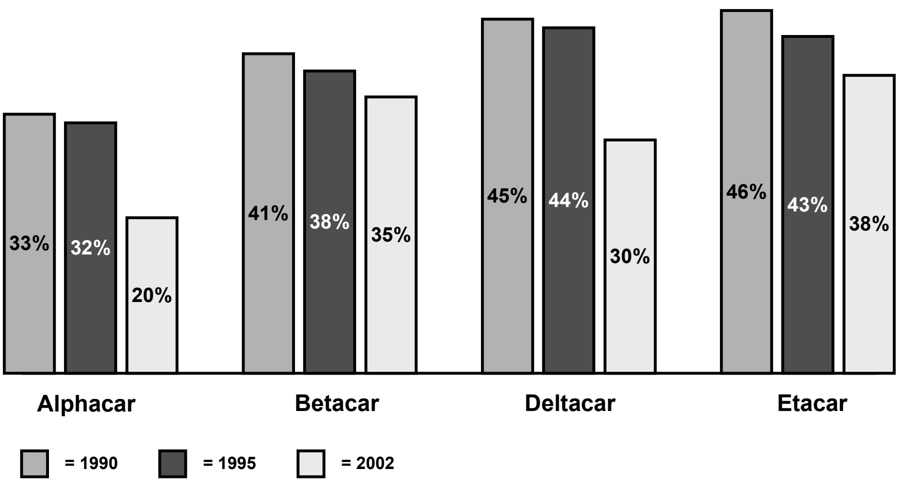
Even though the highly productive Deltacar and Etacar plants would theoretically be able to assemble multiple vehicle models on one assembly line, the personnel and quality costs would have raised substantially. Both OEMs use high-speed mass production processes for the cost efficient production of large volumes. For these processes, shop-floor personnel received specific training in order to perform difficult assembly tasks. The introduction of an additional vehicle model on the same assembly line would require additional training. These costs are relatively high compared to the number of the niche volume produced. For this reason, a specialised contract manufacturer performs the final assembly activities for these niche models. This contract manufacturer is able to consolidate small volumes of different OEMs and can reach scale advantages, which enable a cost efficient production. Furthermore, the process speed of a contract manufacturer is usually lower which reduces failure.

5.5 Extent of vertical integration

In this paragraph the reduction of the extent of vertical integration by the OEMs is analysed, which is considered to influence the relationship between modular sourcing and manufacturing flexibility as a quasi-moderating variable.

An overview of the extent of internally performed value adding activities[32] over the years is depicted in figure 5-8. Based on the initial research findings of Wildemann (1996), these figures were extended.

Figure 5-8: Extent of own activities



Observing the extent of internally performed activities by the OEMs over the years it can be concluded that this has substantially been decreasing. The interviewed managers agreed that the role of modular sourcing has been increasing and is continuing in the future. It should be noted that the extent of activities performed internally as represented in figure 5-8 reflects the OEMs on an aggregated (and not plant) level. In comparison, Alphacar performs the least value adding activities internally (only 20% in 2002). The highest extent of internally performed value adding activities was found at Etacar which reduced this extent by only 17% compared to 1990. Because of the size of its worldwide production

[32] The extent of value adding activities in is expressed in the production costs of a typical vehicle.

network, Etacar is able to use many synergies. Unlike smaller OEMs such as Alphacar, Etacar is able to develop and produce certain modules efficiently within its network. Betacar has remained relatively stable over the years and reduced the extent of internally performed activities by 15% as compared to 1990. A more detailed overview of the manufacturing related activities in the observed plants is given in table 5-7.

Table 5-7: Overview of manufacturing activities

	ALPHACAR	BETACAR	DELTACAR	ETACAR
Body pressing / welding	OEM	OEM	Supplier	OEM
Body coating	OEM	OEM	Supplier	OEM
Final assembly (in the observed plant)	OEM	OEM	Supplier	OEM
Plant logistics	OEM	OEM	Supplier	Supplier
Quality control	OEM	OEM	OEM	OEM

Alphacar and Betacar perform all manufacturing related operations internally, whereas the majority of the modules used in final assembly are developed and produced by the respective module suppliers.

The Alphacar management was sceptic about a far-reaching integration of suppliers in the final assembly operations. Even though it was recognised that this could improve the logistical flexibility, other dimensions of manufacturing flexibility were considered equally important to improve the flexibility of the manufacturing system. Alphacar considers manufacturing as a core activity and does not want to reduce the extent of vertical integration on this level. At the same time, the interviewed managers of Alphacar confirmed the continuing trend of reducing the extent of vertical integration, which is illustrated by the following statement:

> *"… for an SUV model, Alphacar has reduced the extent of vertical integration to a minimum. For this model, Alphacar only performs 10% of the value adding activities (production of engine, gearbox, brakes and final assembly)".*

Even the production of vehicle body frames for this SUV, which traditionally was considered a core operation, is outsourced to a competing OEM. This competitor produces (for cost reasons) the body frames in neighbouring country and transports these modules to the Alphacar plant in Germany where final assembly takes place.

Betacar performs all major manufacturing related activities internally as well. Both internal and external suppliers deliver their modules JIS to the production facility after which Betacar performs the final assembly operations. Like Alphacar, Betacar is equally sceptic about reducing the extent of vertical integration for manufacturing related activities. The production of large volume vehicle models in the observed plant was considered a core activity.

The extent of vertical integration varies depending on the vehicle model and plant observed. For instance, Betacar sources cockpit modules for vehicle model A, either from an internal or external supplier; whereas for model B only an external supplier is used. The internal supplier functions as an independent business unit and offers its products and services primarily within the Betacar production network. Cockpit modules are typically supplied JIS which requires the physical proximity of the supplier to the Betacar plant. Since the external supplier met these requirements and the costs for building a decentralised plant or stocking facility for the internal supplier were relatively high, it was decided to supply these modules from the external supplier.

In the observed plant Deltacar has almost entirely reduced its extent of vertical integration for manufacturing related activities. Deltacar has integrated module suppliers in its production facility in order to reduce costs and increase manufacturing flexibility. Next to the development and production of modules, the module suppliers also perform all final assembly operations. Deltacar merely performs long-term production planning, quality control, and administrative tasks, which represent about 4% of the value adding activities. This 'greenfield' plant'[33] was build in the 1990's and has been the result of learnings made in other logistically optimised plants (see paragraph 5.8).

Etacar has partly reduced its extent of vertical integration for manufacturing related activities. In the observed plant, Etacar optimised the logistical layout and, as a result, has physically integrated the module suppliers into assembly facility. Except for the engine, all modules are developed and produced by external suppliers who directly deliver the goods at the assembly line. Etacar reduced the extent of vertical integration tremendously and only performs about 8% of the value adding activities. This has resulted in an increase of manufacturing flexibility and a reduction of operational assembly costs. Based on these arguments, the following proposition is offered:

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[33] A greenfield plant refers to a plant that was designed without space and infrastructure restrictions.

Proposition 2b: A reduced extent of vertical integration positively influences the relationship between modular sourcing and manufacturing flexibility.

5.6 Process & product know-how

In this paragraph the suppliers' process and product know-how is analysed, which is considered to influence the relationship between modular sourcing and manufacturing flexibility as a quasi-moderating variable.

Specific resources such as experience, people and know-how enable module suppliers to achieve superior organisational performance and enhance the likeliness that a supplier will be selected for a specific project. Such an advantage is in most cases the outcome of a superior cost position. In the analysis it appeared that the process and product know-how of the different supplier types was comparable across the cases. An overview of these competences is given in table 5-8.

Table 5-8: Overview of process and product know-how

	'TYPICAL' CO-SUPPLIER	'TYPICAL' MAIN SUPPLIER	'TYPICAL' MODULE SUPPLIER
Primary area of competence	Process know-how	Product know-how and some process know-how	Extensive process and product know-how
Technological lifecycle	Existing technology	Existing technology / new technology	New technology / new technology
Development of base technology	No	No	Yes, at own risk
Investments in technology	+	+++	+++
Problem solving ability	+	++	+++
Product development	Yes	Yes	Yes
Logistical capabilities	++	++	+++
JIT / JIT variations	JIT	JIT	JIS
Identification of products	Scanning on the box level	Scanning on the box level	Scanning on module level

A typical co-supplier possesses a high level of process know-how and builds on existing technologies. This supplier type primarily aims to reduce processing cost and increase the flexibility of these processes. This enables the development of a competitive advantage in processing less complex products for multiple clients with as little set-up times and costs as possible. The technology-based cost advantages of these suppliers are independent of scale cost advantages. The differences in technology used for processes can create cost differences even when the co-suppliers in question are approximately the same size in terms of production volume. Main suppliers have a high development competence and an adequate level of process know-how. A typical 'module supplier' offers problem-solving competencies and has a high level of process and product know-how. In contrast to co- and main suppliers, module suppliers are more independent and often develop 'base' technologies at their own risk. Moreover, module suppliers even develop new products without a specific problem definition of a buyer.

Module suppliers can take advantage of situations when what they supply is unique and highly differentiated or when the suppliers are not threatened by substitutes. For instance, Betacar faced a situation in which a module supplier developed superior direct fuel injection systems based on a high level of process and product know-how. This module supplier endorsed high prices since no other supplier was able to offer a product of comparable quality. In addition, this supplier enforced quotas for these injection systems and limited the expansion possibilities of Betacar. In order to reduce the dependence, Betacar cooperated with another supplier to develop similar direct fuel injection systems. Only after five years the new supplier was able to produce similar high quality products. As a result, the prices of these direct fuel injection systems dropped after market introduction and a more balanced market situation was re-established. It should be noted that this situation represented an exception and that in most cases multiple suppliers are able to deliver similar quality products. Based on these arguments, the following proposition is offered:

Proposition 2c: **Process and product know-how of a supplier positively influences the relationship between modular sourcing and manufacturing flexibility.**

5.7 Governance choices

In this paragraph the used governance choices are analysed. The use of a less hierarchical coordination structures is considered to influence the relationship between modular sourcing and manufacturing flexibility as a quasi-moderating variable. A typical first step in a vehicle development process is the product-concept-planning (PCP) phase and roughly takes 30-40 months. In the PCP phase, beginning about 5-8 years before a product launch, not only the vehicle concept is chosen according to market and portfolio considerations, but also modules and components that need to be developed, produced, and delivered. Following the first crude drawings of the vehicle and modules, several suppliers are invited to send in competitive beds for the product concept. The concept competition results in proposals that specify design, functionality and materials used. Furthermore, production processes, technology, logistical systems, production location, and target costs are described as well. After several rounds of evaluation, the module supplier is selected after which final negotiations are undertaken and prototype development can be started.

In the development phase, a cross-organisational team for specific modules is formed in which specialists from the OEM as well as the suppliers are represented. This allows the development capacity to be increased in a short period of time and can be reduced again when production is started. These development teams are lead by project manager and remain active until the launch of the vehicle model. It should be noted that the early supplier involvement offers the OEM an opportunity to get insight in the order replenishment, logistics and quality management competencies of the supplier.

Table 5-9: Governance choices in the Alphacar case

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
Initial condition	n.a.	The supplier possesses valuable, hard to imitate and costly capabilities	The supplier possesses valuable, hard to imitate and costly capabilities
Governance choice	n.a.	Market contract	Market contract
Contractual relationship	n.a.	Model life cycle (5-7 years)	Model life cycle (5-7 years)
Supplier management characteristics	Constant improvement of supplier efficiency, the establishment of long-term ties, and work on the internationalisation of supply sources		

Table 5-9 summarises the findings of the selected suppliers for Alphacar. Both the main and module supplier possess valuable, hard to imitate and costly capabilities. Despite the threat of opportunism, classic market contracts are used that specify the estimated number of modules needed in the model life cycle as well as the agreements on price, quality, and delivery. Because Alphacar has a relatively small production volume (as compared to Etacar for instance), the negotiating power of this OEM is limited. As a result, only model life cycle contracts are made. Moreover, the suppliers confirmed that having Alphacar as reference customer is one of the most attractive aspects of a contract.

Alphacar observes supplier management on a strategic as well as operational level. On the primer level mentioned, the focus is on long-term issues such as supplier selection for future model lines and joint capacity planning. This enables the support of current and upcoming vehicles and ensures an optimal integration of suppliers in simultaneous engineering processes. On the other hand, operative supplier management concentrates on the current series in production and day-to-day management (e.g. joint optimisation of the material costs, support in resolving quality and supply problems).

Table 5-10: Governance choices in the Betacar case

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
Initial condition	Uncertainty about the value of the investment	The supplier possesses valuable, hard to imitate and costly capabilities	The supplier possesses valuable, hard to imitate and costly capabilities
Governance choice	Market contract	Market contract	Market contract
Contractual relationship	1 Year	1 Year + extension	Model life cycle (6-8 years)
Supplier management characteristics	Improvement of costs, flexible responses and process security		

Table 5-10 summarises the findings of the selected suppliers for Betacar. The initial condition that determines the choice of governance for the co-supplier is the uncertainty about the value of the investment. In other words, the value remaining flexible in this transaction is high for Betacar. On the other hand, the main supplier as well as the module supplier posses valuable hard to imitate and costly capabilities. The value of gaining access to these capabilities is high despite the threat of opportunism.

For all suppliers Betacar uses market contracts, even though they differ in length. For module suppliers model lifecycle contracts are made which allow the amortisation of development costs over the entire lifecycle production volume. For co- and main supplier standard year contracts are used, with the difference that main supplier contracts are almost automatically extended if adequate performance is achieved. For co-suppliers, year contracts to remain flexible in selecting suppliers in order to ensure the lowest possible price.

The supplier management program of Betacar is focussed on cost improvements, flexibility in responses and process security. In this program, the role of sub-supplier management is increasingly becoming important. Because module suppliers primarily deliver their goods JIS, they in turn are highly dependent on the delivery accuracy lower level suppliers. Therefore, an adequate sub-supplier management is important for process stability of both module supplier and Betacar.

Table 5-11: Governance choices in the Deltacar case

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
Initial condition	Uncertainty about the value of the investment	n.a.	The supplier possesses valuable, hard to imitate and costly capabilities
Governance choice	Market contract	n.a.	Market contract
Contractual relationship	1 Year	n.a.	Model life cycle (6-8 years); compensation based on the number of vehicles ready to be sold
Supplier management characteristics	Equality among parties, mutual trust, cooperation, and high quality		

Table 5-11 summarises the findings of the selected suppliers for Deltacar. The uncertainty about the value of the investment drives the governance choices for co-suppliers. Deltacar wants to remain flexible in their choice for co-suppliers and therefore only uses yearly contracts. On the other hand, the module supplier possesses valuable, hard to imitate and costly capabilities. Despite the threat of opportunism by these suppliers, market contracts are used. In contrast to the co-supplier contract, a model life cycle contract is used for module suppliers. Since the modular consortium of suppliers jointly invested in the observed plant, the costs are amortised over the entire lifecycle sales volume.

Because of its size, Deltacar has a lot of negotiating power in determining the prices for components and modules. For this reason, Deltacar purchases the materials for its module suppliers in order to reduce costs. Only after final assembly and quality control, the module suppliers are compensated. Unlike other approaches, the suppliers in the consortium are only paid after the number of vehicles that are ready to be sold. The modular consortium is based on the equality of the parties involved, mutual trust, and cooperation. Contractual agreements for consortium players not only contain agreements on the volume but also guidelines for participation.

Table 5-12: Governance choices in the Etacar case

	CO-SUPPLIER	MAIN SUPPLIER	MODULE SUPPLIER
Initial condition	Uncertainty about the value of the investment	Uncertainty about the value of the investment	The supplier possesses valuable, hard to imitate and costly capabilities
Governance choice	Market contract	Market contract	Market contract
Contractual relationship	1 Year	1 Year	Model life cycle (6-8 years); compensation based on the number of vehicles ready to be sold
Supplier management characteristics	Helping suppliers in achieving performance in terms of quality, system costs, technology, and delivery effectiveness		

Table 5-12 summarises the findings of the selected suppliers for Etacar. The initial condition that determines the choice of governance for the co-supplier and main supplier is the uncertainty about the value of the investment. Similarly, the module supplier possesses valuable, hard to imitate and costly capabilities. Like the other three OEMs, Etacar uses market contracts for the selected suppliers. A manager of Etacar argued that the insecurity concerning technological developments favours market contracts as well. In other words, because of the uncertainty of a dominant design, OEMs want to remain flexible in selecting their suppliers.

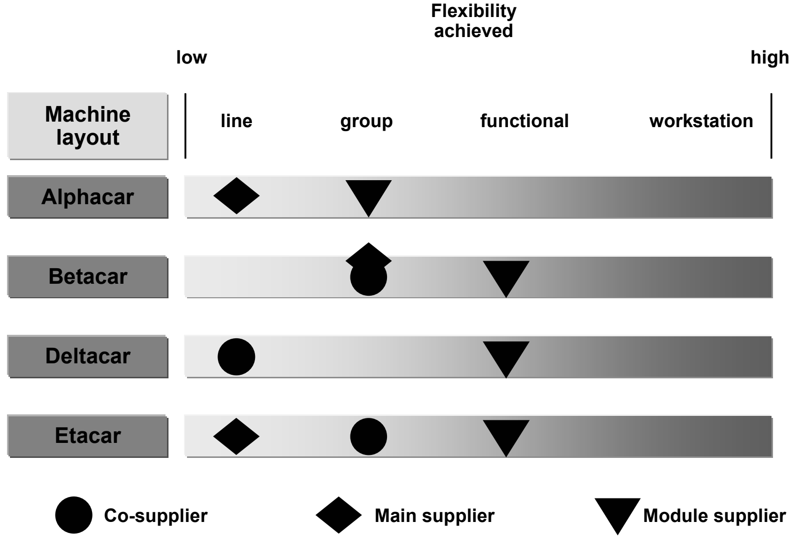
For both the co- and main supplier yearly contracts are chosen in order to remain flexible in the supplier selection and ensure the lowest possible price. The investments made in the Etacar plant by the module supplier are amortised over the vehicle model’s life cycle volume. Like Deltacar, Etacar compensates its integrated module suppliers for the number of vehicles that are ready to be sold. In this compensation a fee for the write-off of the machines is included. At the end of the model life cycle, Etacar will formally own the machines. In contrast to the Deltacar concept, the integrated Etacar suppliers are compensated even if the agreed volumes are not met. On the other hand, if the planned volumes exceed real production, the price of the modules is lowered. Based on these arguments, the following proposition is offered:

Proposition 2d: **Less hierarchical coordination structures between the OEM and supplier positively influence the relationship between modular sourcing and manufacturing flexibility.**

5.8 Process responsibility

In the discussion of moderating factors, it became clear they alone could not explain the challenges Deltacar was facing in its modular consortium. As a consequence, process responsibility was identified as the fifth moderating variable. Based on the analysis of the applied machine layout, the differences in process responsibility can be explained. A summary of the machine layout flexibility achieved by the suppliers is depicted in figure 5-9.

Figure 5-9: Extent of machine layout flexibility

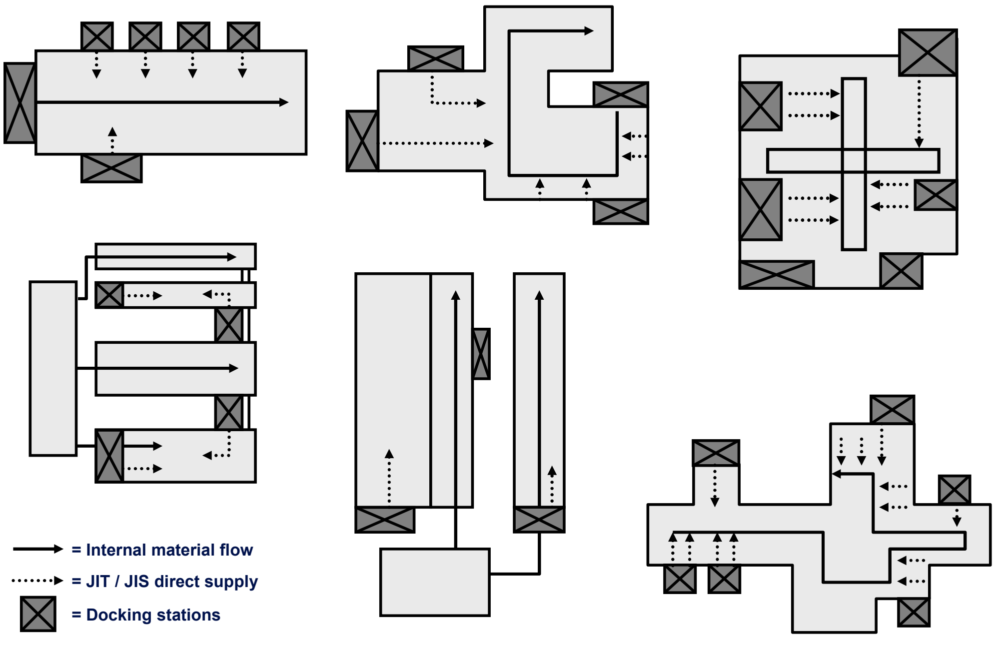


Module suppliers in general use functional machine line layouts that can be considered as more flexible than group or line layouts as applied by co- and main suppliers. The module supplier in the Alphacar case uses a group structure because of the similarities among the modules produced.

The interviewed managers confirmed a high extent of congruence between the process and machine layout. Co- and main suppliers primarily apply mass production processes (see paragraph 5.3.1) in combination with a line or group layout. In such layouts machines are sequentially structured (and additionally grouped) in order to achieve higher productivity levels. A Betacar manager stated that this combination only functions well in situations in which the order flow is relatively stable. Module suppliers primarily use a combination of functional layouts and batch-oriented processes. OEMs primarily use line configurations in combination with mass production processes. However, processes for the vehicle body (stamping, welding, and coating) are batch-oriented (see paragraph 5.3.1), for which group layouts are chosen.

Deltacar and Etacar have been experimenting with different open assembly line architectures to increase flexibility. A selection of different assembly line layouts applied in practice by these two OEMs is depicted in figure 5-10.

Figure 5-10: Overview of assembly line layouts



As can be derived from figure 5-10, open architecture layouts are characterised by a large number of docking stations. Furthermore, conveyor technology, unloading of modules, as well as possibilities to extend the assembly line, were considered in these layouts. Among the interviewed managers, open architecture layouts were considered as more flexible than the traditional designs. A manager of Etacar added:

> *"The open architecture offers the possibility to extend the assembly line when required and gives excellent access to the vehicle during the entire process".*

The primary advantage of the open architecture in the Etacar plant is the possibility of docking-on at multiple points in less than 15 meters of the assembly line. Furthermore, the sub-sections of the assembly line can be operated independently. This allows the set-up of small buffers that enable other subsections to continue working if one subsection suffers a malfunction. However, in an open architectural design the outbound logistical requirements are increased since multiple docking stations have to be visited as opposed to a single one in a traditional design.

In the case of Deltacar, the effort was undertaken to further increase the manufacturing flexibility by integrating the module suppliers in the assembly activities. In order to achieve this, the assembly line and corresponding process responsibility is 'split-up' between the seven integrated module suppliers. The suppliers not only deliver the goods at the assembly line, but also assemble the modules in the vehicle. As the vehicle passes through the different assembly stages, the responsibility of the entire vehicle is transferred from one supplier to the next. This setting created some difficulties for Deltacar and resulted in a reduced stability and productivity of the manufacturing system including quality problems. It was recognised that the root of the problems could be traced back to the failing process 'ownership'. Even though responsibilities may theoretically be clearly separable, in practice it offered challenges. Especially in the case of damages during final assembly and a third party referee (one process owner) would have been necessary. However, in the modular consortium Deltacar has no right to give direct orders to the individual suppliers.

Furthermore, this setting proved to be a source of conflict among participating suppliers especially when one supplier was not able to deliver the required modules. The inability of a supplier to deliver the necessary modules (for whatever reason) usually resulted in the proposal to change the vehicle sequence in order to continue producing. In the consortium, this suggestion would compromise other suppliers planning processes and would also negatively affect overall process stability. Finally, the outsourcing of manufacturing activities to suppliers resulted in the loss of control and the internal feedback mechanism for Deltacar. As a result, the objectives to reduce costs and increase manufacturing flexibility have not been achieved. Based on these arguments, the following proposition is offered:

Proposition 2e: **A reduced process responsibility of the OEM negatively influences the relationship between modular sourcing and manufacturing flexibility.**

5.9 Conclusions

The extent of flexibility achieved by module suppliers in all cases was as good as or higher than those achieved by the co- and main supplies. Therefore, it was concluded that all dimensions of manufacturing flexibility (process, volume, expansion, logistical, product, machine, and personnel) are positively influenced by the application of modular sourcing. Among the 24 interviewed managers (both OEMs and suppliers) it was generally recognised that the level of complexity in the automotive industry has been increasing. Furthermore, the majority of the interviewed managers agreed that the need to reduce investments is strongly related to reducing the complexity costs of vehicles. As a result it was concluded that the extent of complexity affects the relationship between modular sourcing and manufacturing flexibility as a moderating factor. Moreover, the application of modular sourcing reduces the complexity costs for the OEM and aids in improving manufacturing flexibility. In the discussion on complexity, the use of contract manufacturing was considered highly interrelated with the reduction of complexity and costs. Furthermore, outsourcing final assembly activities to a specialised contract manufacturer was considered cost effective for small volumes. The analysis of the internally performed activities by the OEMs over the years indicated a trend towards reducing the extent of vertical integration. It was concluded that this extent can be considered a moderating variable in the relationship between modular sourcing and manufacturing flexibility. As a third moderating factor, supplier process and product know-how was identified. In addition, less hierarchical coordination structure and process responsibility were considered moderating factors as well. Finally, both technological developments and learning curve effects were identified as quasi-moderating variables that enhance the flexibility of the manufacturing system but are not necessarily related to modular sourcing.

6 Survey-based research results

Judgements about flexibility options tend to be subjective and informal. Flexibility levels are rarely monitored or even measured.

(Aaker & Mascarenhas, 1984, p. 75)

6.1 Introduction

In this chapter the survey-based research results are presented that help in answering the secondary research questions (*What dimensions of manufacturing flexibility can be identified and how can they be structured?)* and *(How can manufacturing flexibility be measured?)*. Based on the developed multi-item scales, the propositions concerning the main research construct are validated. The results of the expert opinion survey are presented in paragraph 6.2 followed by the initial scale purification results based on the Q-sorted test and pre-testing of the questionnaire in paragraph 6.3. The respondent's profiles are described in paragraph 6.4 followed by the results of the second purification with a larger set of data. The results of the scale purification are presented in paragraph 6.5. In paragraph 6.6, the developed scale is used to validate of the propositions concerning the main research construct. Finally, paragraph 6.7 summarises the most important conclusions of this chapter.

6.2 Expert opinion interviews

In the chapters 2 and 3, the constructs 'modular sourcing' and 'manufacturing flexibility' have been specified based on an extensive literature review. On this basis, expert opinion interviews were used to validate the domains of these research constructs. These interviews not only provided valuable information for the description of the domain, but also gave input for items that could be used for measuring the constructs.

Expert opinion surveys are personally conducted interviews with the objective to test the theoretical assumptions as well as the proposed definitions of the research constructs. Next to the case study interviews, nine additional experts (both academics and practitioners) were interviewed for the validation of the specified domains[34]. Prior to the actual interviews, specific questions were sent to the experts along with a summary presentation of this study that allowed the experts to prepare for the interview. During the interviews it was necessary to explain both the concept and goals of this study.

The common understanding of modular sourcing and the proposed manufacturing flexibility dimensions was high. The process choice was considered one of the primary drivers for the other dimensions of flexibility. Furthermore, only mass and batch production were considered as relevant for the automotive industry. Two managers stated that in some cases the unit production is appropriate but only for low volume exclusive vehicles brands (e.g. Bugatti, Maybach, Rolls Royce). Furthermore, the inclusion of continuous flow processes was considered relevant for grasping the entire range of process flexibility, yet can primarily be found in other industries (e.g. chemical and oil industry).

Even though expansion flexibility and volume flexibility are regarded as separate dimensions, a high extend of correlation between the dimensions was expected. Long-term investments in new equipment and plant construction automatically influence the long and short-term volume planning. The JIT and JIS factors were considered the most important drivers for a flexible response from a logistical point of view. Two experts argued that logistical flexibility comprised more than the physical proximity and should include the logistical processes as well. One manager pointed out that, from a sales department point of view, logistical flexibility refers to the short-term disposition of the goods and depends on contractual agreements with logistical service providers.

Eight of the experts stated that the extent of flexibility achieved on the product level depends on the role of modular product architectures and platforms used. Product flexibility was expected to largely influence the process design and corresponding process flexibility. Modularity on the product level was considered to increase the level of incremental innovations by separating the component level and architectural learning processes. This confirmed prior research by Sanchez (1998) who stated that modularity has important ‘second order’ effects. Modularity not only enhances innovations but also enables interactive and real-time market research based on analysing customer perceptions to new product variations.

The majority of the experts confirmed that the terms ‘module’ or ‘system’ are often used as synonyms and can be regarded as the highest aggregation of a complex unit. These findings confirmed prior research by Schindele (1996) who concluded that among OEMs and suppliers no uniform definition of modules exists. A plausible reason for these differences is given by (Schindele, 1996) who

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[34] This is in accordance with "stratified sampling" technique for the selection of experts (see Glaser & Straus, 1967).

states that the different supply chain parties value the importance of components differently. For instance, supplier for instrument panels may define this as a system, whereas an OEM defines the entire cockpit (dashboard + instrument panel) as a module. In addition, for more luxurious vehicles (e.g. VW Phaeton, Mercedes Benz S-class, BMW 7 series) the use of electronics is far more important than in smaller vehicle models (e.g. VW Polo, Mercedes Benz A-class, BMW 3 series). Therefore, in the former mentioned vehicle segment a navigation system is considered a standard component, whereas in the latter segment this may be referred to as a module.

Among the interviewed experts, consensus existed as to the role of machine and personnel flexibility. Next to capital, personnel and machines were considered basic resources of an industrial organisation and therefore must exist at the same hierarchical level. Furthermore, a high extent of correlation between the resource level (machine and personnel flexibility) and functional level (process, volume, expansion, logistics, product) was expected. More specifically, a high extent of correlation between machine flexibility and process, volume and expansion flexibility was expected. In addition to this, three experts expected machine flexibility to correlate with product flexibility: the need to acquire new machines may be reduced when they are universally applicable for different products. Personnel flexibility was supposed to support higher-level flexibility dimensions as well. Skilled personnel are able to find solutions for re-routing the flow of production fast and thus supports process flexibility. Furthermore, it was expected that personnel flexibility correlates with volume, expansion, logistical, and product flexibility.

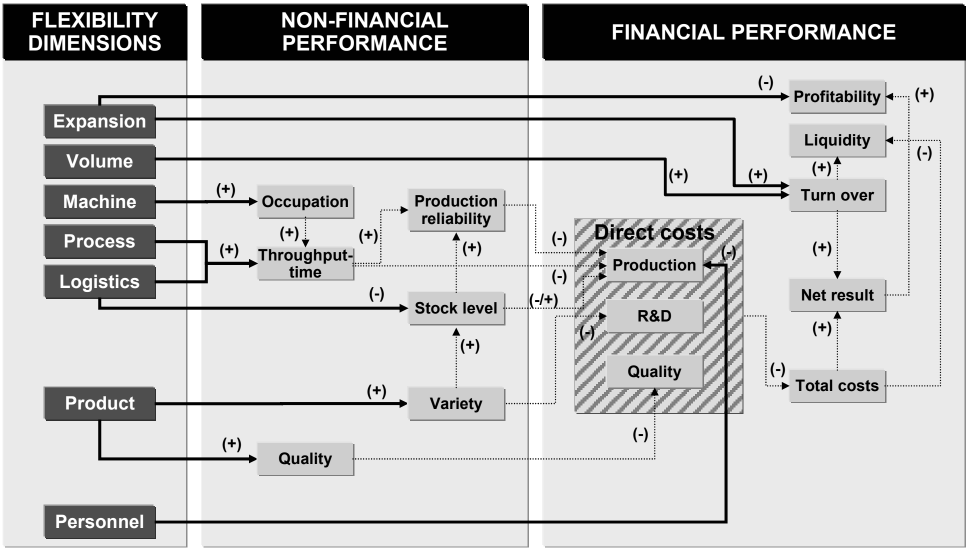
After the analysis of flexibility dimension and their relationships, the effects of increases in these dimensions were discussed. An overview of these effects on financial and non-financial performance criteria is given in figure 6-1 and was initially based on research conducted by Zäpfel & Piekarz (1996). After the identification of the most important performance criteria, the effort was undertaken to indicate relationships among these criteria and their respective nature[35].

Expansion flexibility has a direct negative influence on the profitability of the OEM since increases in this flexibility, by means of long-term investments, will negatively affect the short-term profitability. Like an increase in volume flexibility, expansion flexibility will positively affect the turnover since more products can be produced. Increasing the level of machine flexibility is positively related to the machine occupation. This in turn positively affects the throughput time and will reduce the level of direct production costs. An improvement in throughput time will

[35] A plus indicates a positive impact and a minus a negative one.

positively affect the reliability of the production system and will eventually reduce the direct costs as well. This last part of this argumentation applies to increasing the level of process and logistical flexibility as well. In addition, improvements in logistical capabilities (JIT / JIS) reduce the need for stock, which results in lower costs.

Figure 6-1: Effects of flexibility dimensions of performance criteria



An increase in product flexibility positively affects the variety of the product offerings. At the same time, the variety of modules (that make up the increased product variety) needs to be increased as well. This in turn negatively affects the stock levels and increases the production related costs[36]. At the same time, R&D costs (for the increased variety) will not rise as much as they would if traditional product architectures were used. Modular architectures allow quality problems to be isolated more easily, which in turn reduces the related costs.

Finally, increases in both numerical and functional personnel flexibility reduce the direct production costs. The effects from reduced direct costs

[36] This confirms suggestions made by Argawal *et al.* (2001) who state that build-to-order strategies often result in increased costs.

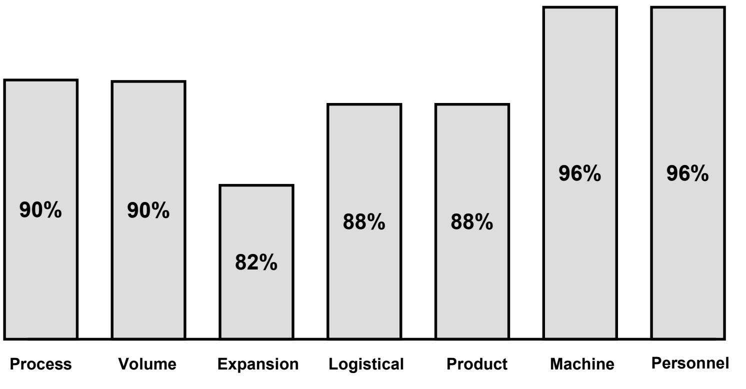
(production, R&D, and quality) are reflected by an increase in the financial performance of the OEM. These interdependencies are not further discussed since they lay beyond the scope of the expert opinion interviews.

6.3 Collection of initial data & scale purification

6.3.1 Q-sorted test

In the performed Q-sorted test (see appendix D) it became clear that often the respondents identified the flexibility dimension associated with a particular scale item correctly. In figure 6-2 the scores for the items that were correctly identified with the dimension are displayed.

Figure 6-2: Scores of the Q-sorted test



Observing the scores on the different dimensions, it can be concluded that the scale items could be grouped best to the machine and personnel flexibility dimensions (in both cases 96%). The overall performance of matching a specific item to the appropriate dimension was fairly good since the lowest score was only 82% for the expansion flexibility dimension. A second Q-sorted test was not considered necessary since a performance of 70% was considered acceptable.

6.3.2 Pre-testing the questionnaire

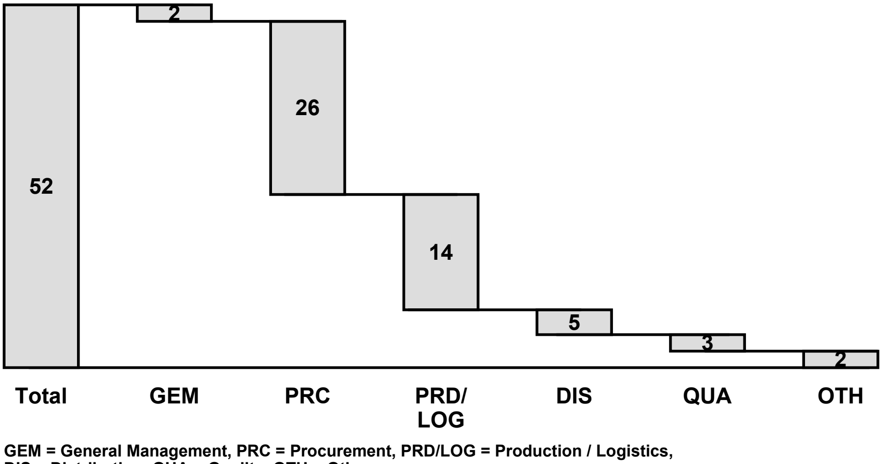
In the pre-testing, a convenience sample of organisations was selected from the sample frame. After personally contacting a knowledgeable respondent, the objective of the study was explained and the person was asked to participate.

These respondents were explicitly asked to give qualitative feedback on questions and clarity of the instructions. The questionnaire was completed by a total of 15 respondents. The qualitative feedback provided was very helpful in the preliminary efforts to assess the reliability of the scales. The coefficient alpha (Cronbach, 1951) was assessed for each scale item as well as the item-to-total correlation. The testing of the initial reliability provided insight in potential problem items. Several items had a low negative item-to-total correlation and were removed from the questionnaire, which resulted in an increase of the Cronbach alpha coefficient. The actions that were taken to resolve some of the initial problems are specified in appendix E. Before finalising the questionnaire, a thorough review of all the items and instructions was undertaken. The cover letters and the resulting questionnaires can be found in appendix F (English) and appendix G (German).

6.4 Response profiles

To collect the necessary data, the questionnaire was send to a convenience sample (n=150), which was selected from the sample frame. Each questionnaire was sent personally to the respondent after a short inquiry in which the person was asked to participate. This technique additionally offered the opportunity to verify the respondent's data. After several follow-ups 52 questionnaires were returned which resulted in an effective response of 35% that is considered acceptable in operations research (Malhotra & Grover, 1998). A summary of the respondent's knowledge level is depicted in figure 6-3.

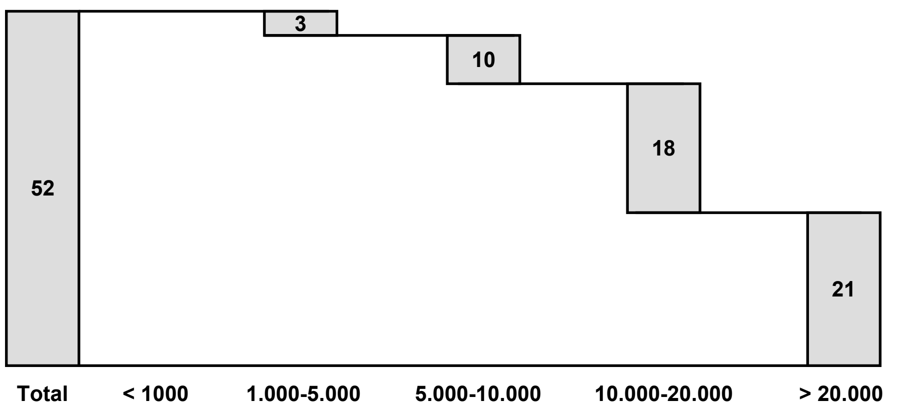
Figure 6-3: Spread of knowledge level



GEM = General Management, PRC = Procurement, PRD/LOG = Production / Logistics,
DIS = Distribution, QUA = Quality, OTH = Other

The targeted respondents for this study are supposed to be 'very knowledgeable' about the module suppliers and operations in the plant. As can be derived from figure 6-3 the majority of the respondents were managers with a procurement, logistics and production background. Furthermore, a limited number of respondents had other functional orientations such as distribution and quality.

Figure 6-4: Spread of organisational size



In figure 6-4 an overview of the organisational size of the valued module suppliers is given. As can be derived from this figure, the majority of the module suppliers examined employ more than 10.000 FTEs. The Chi-square test[37] was used to examine if the spread of organisational size is representative for the sampling frame. Based on this test, the zero hypothesis (the spread in the responses can be compared to the sampling frame) at a significance level of 0,05 can be accepted ($\chi^2 = 15,2$; d.f.= 3).

The testing of the respondent profiles resulted in a good representation of the sample frame. Overall, the objective of creating a good sample was accomplished.

[37] This goodness-of-fit test compares the observed and expected frequencies in each category to test either that all categories contain the same proportion of values or that each category contains a user-specified proportion of values.

6.5 Measurement purification

6.5.1 Overview of purification applied

As recommended by in the Churchill paradigm (1979), scales should undergo a second purification with a larger data set (steps 5 to 8). The purification ensures that measurement properties, such as internal consistency (reliability, unidimensionality), convergence validity, and discriminant validity are adequate for the constructs in this study.

Table 6-1 provides an overview of the validity types observed in this study and is based on a compilation of Venkatraman & Grant (1986), Langerak (1997), and Koste (1999)[38].

Table 6-1: Overview of purification applied

VALIDITY TYPE	CHARACTERISTICS	TECHNIQUES	LITERATURE
Domain validity	The extent to which the empirical measurement reflects the research domain	Literature review, expert opinion interviews, surveys	Nunnally (1978); Hambrick (1983)
Internal consistency			
(i) Unidimensionality	Existence of a single construct that underlies a set of scale items	Exploratory and confirmatory factor analysis[39]	Hair *et al.* (1995); Sharma (1996); Segars (1997); Anderson *et al.* (1987)
(ii) Reliability	Non-measurement failure	Corrected item-to-total correlation, Cronbach alpha	Bagozzi (1980); Cronbach (1951)
Convergence validity	A group of indicators are measuring one common factor	Correlation, confirmatory factor analysis	Bagozzi (1980); Bagozzi & Philips (1982)
Discriminant validity	Scale items measure only the intended construct	Correlation, confirmatory factor analysis	Bagozzi (1980); Hatcher (1994); Segars (1997)

[38] The observation of criterion validity lies beyond the scope of this study.

[39] CFA is useful testing a structure developed a priori whereas EFA can be used in revealing the underlying structure when it is unknown (Venkatraman, 1989).

The domain validation has been discussed in paragraph 6.2 and was accomplished by conducting expert-opinion interviews. In order to test the internal consistency of scales, ‘within block’ analysis was applied (Sharma, 1996; Anderson *et al.*, 1987). This involves the analysis of the (1) corrected item-to-total correlation, (2) unidimensionality, and (3) reliability (Venkatraman & Grant, 1986).

In the analysis, the (1) corrected item-to-total correlations were observed for all items of a single construct. Items without a significant ($p<0,01$) corrected item-to-total correlation and a borderline value of 0,25 were deleted from the scale (Kerlinger, 1973).

The (2) unidimensionality refers to the existence of a single construct that underlies a set of scale items (Hair *et al.*, 1995, Segars, 1997). Factor analysis with the use of the principal component extraction method has been applied to determine if the scales show unidimensionality. Furthermore, the ‘eigenvalues’ of the construct as well as the factor loadings have been assessed (Steward, 1981; Sharma, 1996). According to Steward (1981) eigenvalues larger than 1,0 and factor loading larger than 0,5 should be used. Furthermore, several indices such as the goodness-of-fit indicator (GFI) and the recently developed root mean square error of approximation (RMSEA) can be used to test the overall fit. These indices do not depend on sample size explicitly and measure how much better the model fits as compared to no model at all[40]. For the GFI, the borderline value is 0,9 whereas for the RMSEA, a value less than 0,08 is desirable (Brown & Cudeck, 1993).

The (3) reliability of a scale is demonstrated if the items are highly correlated with each other and with the total scale (Hair *et al.*, 1995). The reliability can be tested using the Cronbach alpha coefficient (Cronbach, 1951) for multi-item scales and the interrater reliability coefficient (James *et al.*, 1984) for single-item scales. The Cronbach alpha coefficient provides a summary of the correlations that exist among a set of items. In other words, Cronbach's alpha measures how well a set of items measures a single construct. For established scales, a coefficient alpha of 0,70 is considered acceptable, while 0,50 or greater is acceptable for new scales (Nunnally, 1978).

Bagozzi & Philips (1982) define convergence validity is defined as:

> *“The degree to which two or more attempts to measure the same concept are in agreement (Bagozzi & Philips, 1982, p. 468)”*

[40] Other ‘fit’ indices that could be used are the relative-non-centrality index (RNI) and Tucker Lewis index (TLI). The borderline value for these indices is 0,9 (Sharma, 1996).

In other words, convergent validity exists if a group of items measure one common factor and can be assessed with several methods. First of all, the average variance extracted (AVE) of 0,5 or higher indicates that the items are explaining more of the variance than is due to measurement error (Segars, 1997). Furthermore, squared standard loadings larger than 0,5 for the individual items indicate convergent validity as well (Koste, 1999). Finally, the ratio of factor loadings to their respective errors (t-value) can be used for examining convergent validity. If these t-values are greater then |2,0|, they are significant at the 0,05 level (t-value=1,96; p=0,05) (Koste, 1999).

Discriminant validity applies if scale items measure only the intended construct. In other words, the items should not load significantly on other constructs. By its nature, discriminant validity must be examined between two or more constructs. If the AVE for each construct is greater than the squared correlations between constructs (between construct variance) then discriminant validity is demonstrated (Hatcher, 1994; Segars, 1997). In other words, discriminant validity applies when the correlations between the constructs significantly differ from 1,0 (Bagozzi, 1980).

6.5.2 Results of purification

The purification of the scale items included the examination of the internal, convergence and discriminant validity. Table 6-2 provides a summary of the purification results[41].

Table 6-2: Summary of internal consistency and convergent validity

FACTOR	NUMBER OF ITEMS	MEANS	VARIANCE	MINIMAL ITEM-TO-TOTAL CORRELATION	CRONBACH ALPHA
Process	4	4,18	0,01	0,46	0,74
Volume	3	4,09	0,01	0,63	0,82
Expansion	3	4,26	0,01	0,38	0,64
Product	4	4,05	0,01	0,56	0,83
Logistics	2	4,45	0,01	0,47	0,64

[41] See Appendix H for the detailed results.

FACTOR	NUMBER OF ITEMS	MEANS	VARIANCE	MINIMAL ITEM-TO-TOTAL CORRELATION	CRONBACH ALPHA
Machine	5	4,25	0,01	0,62	0,88
Personnel	2	4,13	0,01	0,67	0,80
Modular sourcing	2	4,19	0,01	0,62	0,76

In the purification process, several scale items had to be removed (PRC_02, PRC_08, VOL_01, VOL_03, VOL_08, EXP_05, PRO_01, PRO_03, PRO_07, LOG_03, MAF_04, MAF_05, MAF_08, PER_01, PER_03, PER_05, MOD_01, MOD_04) since insufficient performance was demonstrated. The remaining scale items exhibited unidimensionality, reliability, and an adequate level of convergent validity, based on the criteria as described in paragraph 6.5.1.

Discriminant validity was examined for the manufacturing flexibility dimensions and their scale items. Discriminant validity exists if the average variance extracted (AVE) by a construct is greater than the variance between this construct and the other constructs. These variances are displayed in table 6-3. The diagonal cells contain the within-construct variances, while the off-diagonal cells contain the between-construct variances.

Table 6-3: Summary of discriminant validity

	PRC	VOL	EXP	PRO	LOG	PER	MAF	MOD
PRC	**0,68**							
VOL	0,24*	**0,61**						
EXP	0,01	0,18	**0,45**					
PRO	0,13	0,26*	0,02	**0,64**				
LOG	0,00	0,07	0,17	0,29*	**0,68**			
PER	0,05	0,10	0,13	0,20	0,11	**0,88**		
MAF	0,12	0,26*	0,14	0,04	0,11	0,07	**0,79**	
MOD	0,28*	0,35**	0,26*	0,48**	0,33**	0,24*	0,09	**0,73**

Two-tailed Pearson correlation matrix (off-diagonal):
* Correlation is significant at the 0,05 level
** Correlation is significant at the 0,01 level

As can be derived from table 6-3, the between construct variances were lower than 1,0 and less than the within-construct variances thus indicating discriminant validity. Therefore, it can be concluded that after the measurement refinement, the remaining 25 scale items indicated a sufficient degree of unidimensionality, reliability, convergence validity, and discriminant validity.

6.6 Validation of main research construct

The developed, psychometrically sound scales can now be used to validate the propositions made in chapter 5 concerning the main research construct (the relationship between modular sourcing and the manufacturing flexibility dimensions).

Given the small sample size, ordinary least squares regression analysis was used to test the hypothesised relationships. Before estimating each relationship, the variance inflation factor (VIF) was computed for each independent variable to assess multicollinearity[42]. A VIF value close to 1,0 indicates little or no multicollinearity, whereas a range between 1,0 and 2,0 indicates a moderate degree. The results of the regression analysis are depicted in table 6-4.

Table 6-4: Results of regression analysis

CONSTRUCT	ß-COEFFICIENT	STANDARD ERROR	T-VALUE	VIF
PRC_SUM	0,26	0,13	1,93	0,06
VOL_SUM	0,21	0,13	1,59	0,12
EXP_SUM	0,24	0,16	1,54	0,13
LOG_SUM	0,24	0,14	1,69	0,10
PRO_SUM	0,29	0,12	2,39	0,02
MAF_SUM	0,19	0,14	1,40	0,17
PER_SUM	0,21	0,13	1,56	0,13
MODEL SUMMARY		ADJUSTED R^2	STANDARD ERROR OF THE ESTIMATE	DURBIN-WATSON
		0,45	**0,53**	**1,76**

[42] VIF is the reciprocal of the tolerance. As the variance inflation factor increases, so does the variance of the regression coefficient, making it an unstable estimate. Large VIF values are an indicator of multicollinearity.

The regression model indicates an acceptable goodness-of-fit (adjusted R^2). Furthermore, the analysis of the residuals shows a weak form of autocorrelation, which is reflected by the Durbin-Watson statistic[43].

The results from the survey support P_{1a} since modular sourcing positively influences process flexibility (*ß = 0,26; p < 0,05*). This suggests that the less regulating modes of production, increases the level of flexibility achieved. The results support P_{1b} as modular sourcing positively influences volume flexibility (*ß = 0,21; p < 0,10*). In other words, the aggregate output that is achieved by a particular manufacturing system is positively influenced by the application of modular sourcing. Similarly, the proposition P_{1c} is supported as well since modular sourcing positively influences expansion flexibility (*ß = 0,24; p < 0,10*). The variety of expansions in the manufacturing system is significantly correlated with the application of modular sourcing. The proposition P_{1d} is supported by the survey results since modular sourcing positively influences logistical flexibility (*ß = 0,24; p < 0,05*). The importance of JIS supply and the proximity of module suppliers to the OEM were significantly correlated with the application of modular sourcing. The results support P_{1e} as modular sourcing positively influences product flexibility (*ß = 0,29; p < 0,05*). The variety of products offered and the ability to adjust functionality determine product flexibility. The capability of making functional or engineering design changes is enhanced by the application of modular sourcing. The proposition P_{1f} is supported by the survey results since modular sourcing positively influences machine flexibility (*ß = 0,19; p < 0,10*). The correlation between modular sourcing and the variety of operations a machine can perform (without requiring a prohibitive effort in switching from one operation to another) is significant. Finally, the results support P_{1g} as modular sourcing positively influences personnel flexibility (*ß = 0,21; p < 0,10*). The training of personnel in order to perform additional tasks is significantly correlated with the application of modular sourcing. This is understandable since personnel should be able to quickly adopt new tasks when it is decided to change the extent of vertical integration.

6.7 Conclusions

In this chapter, the survey-based research results were presented. Expert opinion interviews were used to validate the domains of these research constructs. Among the interviewees, the common understanding of the flexibility dimensions and corresponding hierarchy was high. The process choice was considered one of the primary drivers for the other dimensions of flexibility. Even though expansion

[43] Ideally, the expected value of the Durbin-Watson statistic is 2.

flexibility and volume flexibility were regarded as separate dimensions, a high extend of correlation between these dimensions was expected. The JIT factor was considered one of the most important drivers for a flexible response from logistical point of view. Product flexibility was expected to largely influence the process design and corresponding level of process flexibility. Moreover, modularity on the product level was considered to increase the level of incremental innovations by separating the component level and architectural learning processes. Machine and personnel flexibility were considered as basic organisational resources and were expected to support the higher-level flexibility dimensions. A final step in the expert opinion interviews was the analysis of the effects of increased levels of flexibility on several financial and non-financial performance criteria. These interviews not only provided valuable information for the description of the domain, but also gave input for items that could be used for measuring the constructs. After the development of scale items for the research constructs, the quality of these items was tested in two phases. Furthermore, a larger scale data collection was carried out to purify the measures for a second time. As a result, several items were deleted in accordance with Churchill's procedure for "developing better marketing constructs" (1979). The second round of purification was applied to ensure that measurement properties such as internal consistency (reliability, unidimensionality), convergence validity, and discriminant validity were adequate for the constructs. The purified scale was used to validate the propositions concerning the main research construct (the relationship between modular sourcing and manufacturing flexibility). After conducting regression analysis it was concluded that all seven dimensions of manufacturing flexibility were positively influenced by the application of modular sourcing.

7 Conclusion, discussion & recommendation

Historically, managers designed and redesigned organisations by making modifications to traditional bureaucratic forms on the basis of intuition, past experiences, imitation, personal attitudes and preferences. The design of organisations that are flexible, that adapt and create change, that more fully use both human and technological resources, and that are global in scope, are perhaps the most significant variables of the new forms. Strategies for hyper competitive environments can only be undertaken within the limits enabled by organisational forms. New organisation forms open up new sources of sustained competitive advantage.

(Daft and Lewin, 1993, p. ii)

7.1 Introduction

As stated in the introductory chapter, the primary objective of this study is to contribute to a better understanding of the relationship between modular sourcing and manufacturing flexibility in the automotive industry. In order to achieve this, a conceptual framework is developed in which the effects of modular sourcing on seven manufacturing flexibility dimensions is displayed. The inclusion of seven dimensions corresponds to the general understanding of manufacturing flexibility as a multi-dimensional concept.

The relationships between the research constructs have been explored in exploratory case studies (chapter 5) and were validated in the survey (chapter 6). In this chapter the synthesis between theory and practical research results takes place. Following this introduction, the main conclusions for this study are drawn and answers to the posed research questions are given in paragraph 7.2. In this paragraph, the proposed conceptual framework is discussed based on the case study findings and the survey-based research. In paragraph 7.3 the research results are discussed and compared to the theoretical framework as developed previously. In the analysis of the research constructs, the role of organisational strategy and industry structure needs further merit. Paragraph 7.4 discusses the learnings drawn from the chosen research strategy (as discussed in chapter 4). The implications and recommendations for future research are discussed in paragraph 7.5. Finally, in paragraph 7.6 the implications of modular sourcing on manufacturing flexibility for management are discussed. This final section provides managers insight in the dangers of outsourcing too many activities.

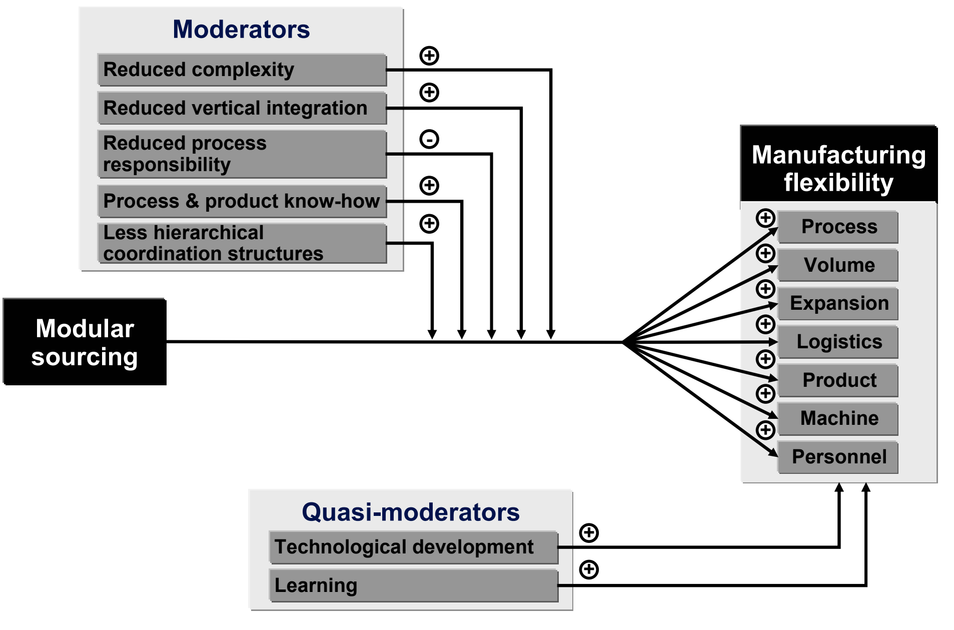
7.2 Main conclusion

The primary research question, as posed in chapter 1, can be answered based on the research results in the chapters 5 and 6.

What are the effects of modular sourcing on manufacturing flexibility in an automotive supply chain?

Modular sourcing has a positive effect on the level of process, volume, expansion, logistical, product, machine, and personnel flexibility achieved (see figure 7-1).

Figure 7-1: Validated conceptual framework



First of all, the application of modular sourcing positively affects the level of process flexibility achieved. This relationship has been confirmed in the case studies as well as the survey based research ($ß = 0,26; p < 0,05$). Module suppliers primarily apply batch production, which entails a higher extent of flexibility than the mass production processes as chosen by co- and main suppliers. Co- and main suppliers primarily aim to reduce production costs as much as possible. Consequently, these suppliers primarily mass production processes. Mass production is the primary process choice of Alphacar, Betacar, Deltacar, and Etacar as well. The unit production process only applies to some low volume exclusive vehicles brands of these OEMs. Furthermore, combinations of process choices can be found in the manufacturing system of both the OEM and module supplier. This is in alignment with empirical research conducted by Woodward (1965), who concluded that different technologies impose different demands on organisations, which have to be met using the appropriate structures and process choices. Furthermore, the refinements on the process flexibility scale by critics of Woodward (e.g. Starbuck, 1965; Hunt, 1970) proved to be adequate and were valuable for determining intermediate process choices.

Second, the application of modular sourcing positively affects the level of volume flexibility achieved. In the case studies it was confirmed that volume flexibility allows organisations to respond to both decreases and increases in the aggregate demand at a given configuration. Furthermore, the positive relationship between modular sourcing and volume flexibility was confirmed by the survey as well ($ß = 0,21; p < 0,10$). The short-term volume flexibility is vital to the stability of manufacturing system of the module supplier as well as the OEM. Furthermore, the notion of Krajewski & Ritzman (1996) to observe the effective capacity under normal conditions instead of that under maximal occupation, proved to be important in determining the actual levels of volume flexibility achieved.

Third, the application of modular sourcing positively affects the level of expansion flexibility achieved. Expansion flexibility is not confined to the current resources available and is related to increasing the capacity or capability of the manufacturing system in the long-term. Like the case study results, the survey confirmed that modular sourcing is positively related with expansion flexibility ($ß = 0,24; p < 0,10$). Furthermore, expansion flexibility has important implications for the competitive position of OEMs and suppliers. If an organisation is able to consider long-term demand changes (e.g. because of changes in the business environment) in the expansions that are made, the competitive position can be enhanced. Long-term expansion flexibility is related to the strategic planning for which short-term volume fluctuations are indicators. It is important to observe that an effective use of the production network not only enables volumes to be swapped between manufacturing systems, but also reduces the need for equipment. This production network relies heavily on the logistical accuracy in which JIT, JIS and synchronic manufacturing need to be controlled across plants.

Fourth, the application of modular sourcing positively affects the level of logistical flexibility achieved. This relationship was explored in the case studies and has been confirmed by the conducted survey ($ß = 0,24; p < 0,05$). Logistical flexibility refers to the ability to supply modules in a very short time interval when disturbances occur (Rieken, 1995). The case studies indicated that just-in-time (JIT) and just-in-sequence (JIS) supply are extremely crucial to the extent of logistical flexibility achieved. Co- and main suppliers use the principles of JIT in order to supply their goods, whereas module suppliers primarily use JIS supply. In order to increase the process stability for JIT and JIS supply, a physical proximity of the supplier to the OEM is necessary. Therefore, the ‘greenfield’ plants observed for Deltacar and Etacar, allow the integration of module suppliers on the premise, thereby optimising the logistical process stability. Both the in- and outbound flow of the goods were observed in determining the extent of logistical flexibility. This is in accordance with suggestions made by Striening (1991) and Horvath *et al*. (1993), who state that a functional separation between in- and outbound flexibility leads to design problems of the logistical function and the ability to grasp its flexibility.

Fifth, the application of modular sourcing positively affects the level of product flexibility achieved. This relationship was explored in the case studies and has been confirmed by the conducted survey ($ß = 0,29;\ p < 0,05$). Product flexibility refers to the ease with which specifications can be changed for newly introduced or existing products. Module suppliers are comparatively more flexible than co- and main suppliers, because the primer mentioned supplier has a high level of process as well as product know-how. The capability of making functional or engineering changes can be determined by observing the ability to handle difficult, non-standardised orders. Furthermore, the ability to add or substitute new parts gives an indication of this capability as rightly suggested by Gupta & Somers (1996). Since the observed OEMs produce relatively standardised products that only minimally vary in local markets, component sharing and swapping modularity are considered sufficient[44] in the automotive industry. The notion of Pine (1993) that consumers could perceive some sets of modularised products as too similar was confirmed in the case studies and expert opinion interviews. For this reason, OEMs offer a large variety of vehicle features which consumers find most personal (e.g. interior, technical comfort options).

Sixth, the application of modular sourcing positively affects the level of machine flexibility achieved. This relationship was explored in the case studies and has been confirmed by the conducted survey ($ß = 0,19;\ p < 0,10$). From the case studies can be derived that module suppliers heavily invest in technological advanced machines that are able to perform highly specialised tasks and can be re-programmed easily. The use of cost intensive universal machines allows module suppliers to generate scale advantages even though the products produced for different clients may differ extensively from each other. On the other hand, the co- and main suppliers primarily use multi-purpose machines that allow

[44] Component sharing/swapping modularity refers to the use of the same component across multiple product ranges (see Abernathy & Utterback, 1978).

these suppliers to create scale advantages as well, yet with a smaller range of products. These machines have comparatively long set-up times and are able to perform a limited number of specialised operations. Spingler & Bäßler (1984) rightly stated that the use of simplified components in machines largely determines these re-tooling times and not only applies to the actual assembly stations but also to the inter-linkage of machines. These findings are consistent with the contemplation model as developed by Moerman (1998), in which the different types of machines correspond to the process choices.

Seventh, the application of modular sourcing positively affects the level of personnel flexibility achieved. This relationship was explored in the case studies and has been confirmed by the conducted survey ($\beta = 0,21; p < 0,10$). From the case studies can be derived that module suppliers reach at least equal or higher levels of personnel flexibility as compared to co- and main suppliers. Morroni (1991) rightly stated that European organisation use a combination of numerical and functional flexibility which in turn depends on the cultural context. However, in the case studies it became clear that the functional personnel flexibility was considered more important than numerical flexibility for the observed OEMs. Furthermore, increasing the functional flexibility by training, education, and job rotation have motivational aspects as well. A motivated employee is more consistent in the performance outcomes and even may increase the number of tasks he/she can perform, for personal satisfaction.

Based on the research findings, the following secondary research questions can be answered as well:

What moderating and quasi-moderating variables can be identified that influence the relationship between modular sourcing and manufacturing flexibility?

In this study, the following five moderating variables have been identified that influence the relationship between modular sourcing and manufacturing flexibility: reduced complexity, reduced vertical integration, process and product know-how, reduced process responsibility, and less hierarchical coordination structures. On the other hand, technological development and learnings made influence the level of manufacturing flexibility without that they are necessarily related to modular sourcing. Therefore, these two aspects can be regarded as quasi-moderating variables.

First of all, the reduction of complexity and related costs positively influences the relationship between modular sourcing and manufacturing flexibility. The outsourcing of module development and production reduces the extent of complexity for the OEM and allows a focus on their core activities. However, it is important to observe that the complexity cost are merely transferred to the module supplier and are not reduced from a supply chain point of view. Furthermore, the negative effects of the complexity trap as described by Boutellier *et al.* (1997) were confirmed in the case studies. It became clear that the effects of reduced complexity do not instantly become apparent. Since the complexity related costs are transferred to the module supplier, the negative effects of the time-delay between cause and effect are shifted as well. Finally, in alignment with Adam & Johannwill (1998) and Piller & Waringer (1999) the quantification of complexity related costs proved to be difficult.

Second, the reduction of vertical integration influences the relationship between modular sourcing and manufacturing flexibility. The analysis of the activities internally performed by OEMs over the years reveals the increasing important role of modular sourcing applications and a trend towards a reduction of the extent of vertical integration. For instance Alphacar has reduced the extent of internally performed activities by the highest extent (80%) and in the future is reducing this even further (about 90%). In alignment with the 'resource-based view of the firm' (Penrose, 1959; Learned *et al.*, 1969; Barney, 1991) it can be argued that the development and production of modules are not considered core operations of an OEM. Despite the threat of opportunism, OEMs consider the value created by working with module suppliers as higher than the value that would be created if the organisation was vertically integrated. Therefore, it can be concluded that the threat of opportunism is not the only decision ground for make-or-buy decisions.

Third, superior process and product know-how of the module supplier positively influences the relationship between modular sourcing and manufacturing flexibility. In accordance with the 'resource-based view of the firm' (Penrose, 1959; Learned *et al.*, 1969; Barney, 1991) it can be concluded that the source of an organisational competitive advantage lies in those activities, which an organisation is able to conduct in a superior manner as compared to others. Specific resources such as experience, people and know-how enable module suppliers to achieve superior organisational performance based on process and product know-how. Such an advantage is the logical outcome of a superior cost position achieved by this supplier.

Fourth, less hierarchical coordination structures positively influence the relationship between modular sourcing and manufacturing flexibility. In most cases market type contracts are used to coordinate the relationship between the module supplier and OEM. The governance choices for co-supplier and main supplier are primarily driven by the uncertainty concerning the value of the investment, which is in alignment with the real option theory. Furthermore, the fact that module supplier possesses valuable, hard to imitate and costly capabilities is a compelling reason for using market structures despite the threat of opportunism. Even though a module supplier possesses valuable resources, it may still be possible to acquire it. However, the cost of acquisition in these situations may be greater than the value of such an acquisition, which is often reflected in the marketplace by lower stock prices after completing the acquisition (Barney, 2001). Most module suppliers and its capabilities and resources are valuable exactly because they are not owned by another organisation (Kanter, 1993). Observing these arguments, it can be concluded that when a set of business functions is likely to be a source of competitive advantage, OEMs have to manage this (when possible) through more hierarchical governances. If, on the other hand, business functions are not likely to be a source of competitive advantage then it is possible to manage this in non-hierarchical governance structure, which is consistent with the transaction cost theory.

Fifth, the reduction of process responsibility negatively influences the relationship between modular sourcing and manufacturing flexibility. This effect has been derived from the Deltacar case and is supported by many other researchers (e.g. Goldratt, 1994; Deming, 2000) who described the importance of process ownership to the stability of the manufacturing system in other industries. In the observed plant Deltacar integrated its module suppliers in assembly plant, which tremendously improved the logistical flexibility. However, the manufacturing process responsibility was transferred to these module suppliers as well in order to reduce costs and increase flexibility and efficiency. This transfer of responsibility had a reverse effect and actually decreased the stability and productivity of the manufacturing system. In other words, the failing process ownership of Deltacar was considered the root of these problems.

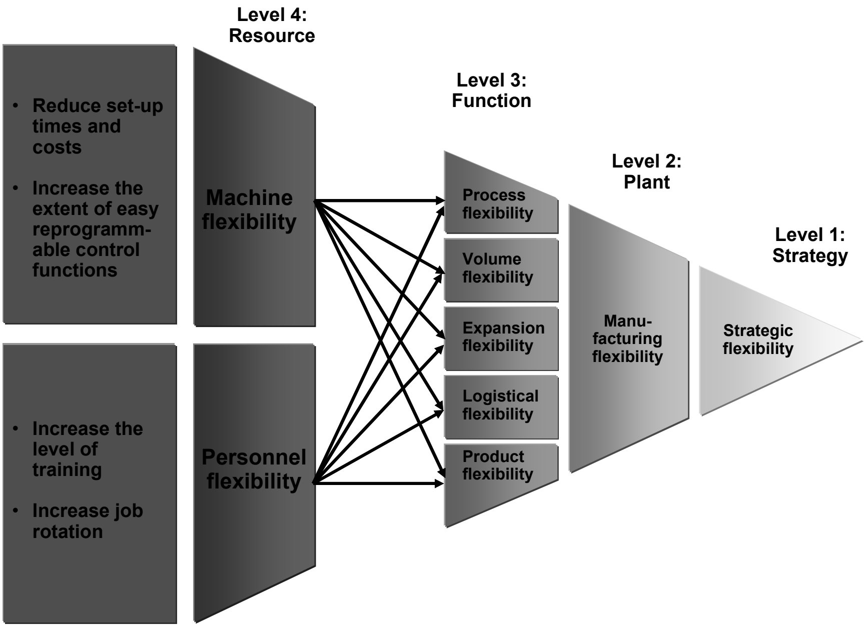
Technological development and learnings made are considered as quasi-moderating variables in the conceptual framework and were identified based on the resource-based theory of the firm (Penrose, 1959; Learned *et al.*, 1969; Barney, 1991). First of all, technological developments can be implemented in the manufacturing system independent of the decision to apply modular sourcing. These developments can include, a wider range of products that can be produced on the same machine, a reduction of set-up and retooling times, and increased performance in terms of throughput time.

From the case studies can be derived that learning curve effects play an important role in the improvement of the flexibility of the manufacturing system. This confirms research by Henderson (1974) who additionally stated that the first organisation that moves down the learning curve will obtain a cost advantage, which is reflected by a higher performance level of the manufacturing system. However, this argumentation assumes that the products produced are immediately sold to customers. Manufacturing to increase inventory may reduce the production costs but will lead to the negative performance of the organisation as a whole. Thus, to go down the learning curve and obtain cost advantages, organisations must aggressively acquire market share.

What dimensions of manufacturing flexibility can be identified and how can they be structured?

Based on the case studies, expert opinion interviews, and survey, the following seven dimensions of manufacturing flexibility were identified: process, volume, expansion, logistical, product, machine, and personnel. These dimensions jointly comprise the entire domain of manufacturing flexibility and are part of a hierarchy (see figure 7-2).

Figure 7-2: Manufacturing flexibility hierarchy



Machine and personnel flexibility are considered as building blocks for the other flexibility dimensions in this hierarchy. Manufacturing flexibility builds on specific plant functions (e.g. material sequencing, production flow routing) and resources to support the strategic level. In order to achieve a higher level of strategic and plant level flexibility, an appropriate mix of functional dimensions (process, volume, expansion, logistical, product) needs to be developed. Thus, in order to improve the functional flexibility dimensions, the organisation has to start by improving the resource level. Moerman (1998) confirms this and states that organising the resource level is the basis for improving operational efficiency.

Measures such as the reduction of machine set-up times and costs, as well as an increase in the extent of easy re-programmable control functions, will have a direct effect on the higher-level flexibility dimensions. Similarly, increases in the level of training and job rotation will directly impact the higher-level flexibility dimensions as well. Support for this conception can be found in both conceptual and empirical research. Empirical support exists for machine flexibility with process flexibility (Sethi & Sethi, 1990; Koste, 1999), volume flexibility (Suarez *et al.*, 1995), expansion flexibility (Sethi & Sethi, 1990; Hyun & Ahn, 1992). Conceptual support exists for machine flexibility and logistical flexibility (Eicke & Femerling, 1991; Gries, 1994; Wolters, 1995), and product flexibility (Beckman, 1990; Chen *et al.*, 1992). Similarly, conceptual support exists for personnel flexibility with process flexibility (Koste, 1999), volume flexibility (Chen *et al.*, 1992; Huyn & Ahn, 1992; Suarez *et al.*, 1995), expansion flexibility (Hyun & Ahn, 1992), logistical flexibility (Eicke & Femerling, 1991; Wolters, 1995), and product flexibility (Huyn & Ahn, 1992).

How can manufacturing flexibility be measured?

As a basis for testing the proposed relationships between modular sourcing and the seven operational dimensions of manufacturing flexibility, a multi-item scale was developed which can be found in Appendix I. In order to develop this multi-item scale the framework of Churchill (1979) has been used. This framework consists of eight steps and is widely accepted by researchers (e.g. Flynn *et al.*, 1990; Langerak, 1997; Koste, 1999).

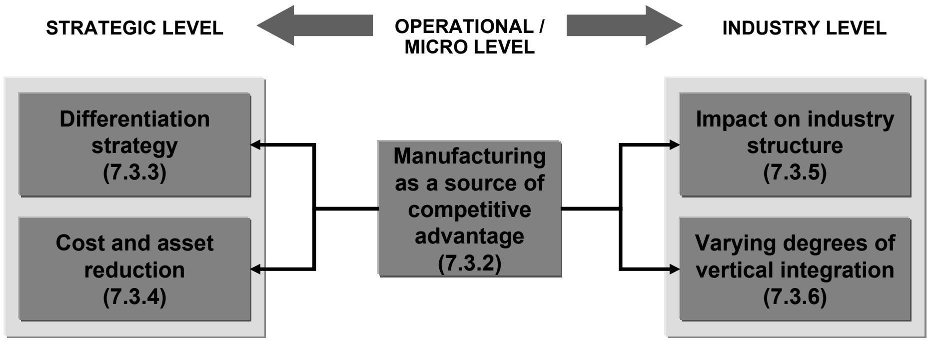
For each of the described flexibility dimensions (process, volume, expansion, logistics, product, machine, and personnel), scale items have been generated based on the available literature, case studies and expert opinion interviews. After testing and purification of these measures they show an adequate levels of internal consistency (reliability, unidimensionality), convergence validity, and discriminant validity.

7.3 Discussion

7.3.1 Introduction

After discussing the unpredictability, uncertainty, and complexity of the industrial environment, the applied business strategies in the automotive industry were addressed. However, the primary level of analysis in this study is on the industrial organisation and it's manufacturing system. On this micro operational level, the lower hierarchical dimensions of manufacturing flexibility levels are observed. On this micro level, machine and personnel flexibility are considered as basic building blocks for 'functional' levels such as: process flexibility, volume flexibility, expansion flexibility, logistical flexibility, and product flexibility. In this paragraph the micro analytical level is used as a discussion platform in order to derive the impact on the chosen business strategy and industry structure. The structure of this discussion paragraph is displayed in figure 7-3.

Figure 7-3: Schematic representation of the discussion section



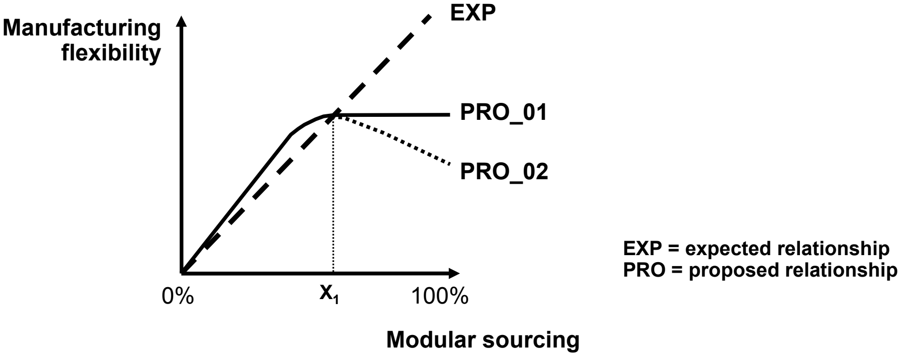
As a basis for discussing the impact on a strategic and industrial level, manufacturing operations as a basis for achieving a competitive advantage is addressed in paragraph 7.3.2. Next, the implications on the differentiation strategy will be addressed in paragraph 7.3.3, followed by the discussion of cost and asset reduction in paragraph 7.3.4. In paragraph 7.3.5 the effects of modular sourcing on the industry structure are discussed. Finally, the differences in extent of vertical integration are addressed in paragraph 7.3.6.

7.3.2 Manufacturing as a source of competitive advantage

Manufacturing as a basis to increasing organisational flexibility and efficiency is often underestimated. In this paragraph the relative strength of the moderating variables on the relationship between modular sourcing and manufacturing flexibility is discussed.

As was described in paragraph 7.2, modular sourcing has a positive influence on the level of manufacturing flexibility. Therefore, the expected relationship (EXP) between modular sourcing and manufacturing flexibility is considered linear in figure 7-4. In other words, an increase in the level of modular sourcing increases the flexibility of a particular manufacturing system.

Figure 7-4: Effects of moderating variables



As described in chapter 5, all moderating variables (except for the reduced process responsibility) have a positive influence on the relationship between modular sourcing and manufacturing flexibility. This confirms research findings of Brandes *et al.* (1997) and Heshmati (2000) who conclude that increasing the level outsourcing has a direct and positive effect on manufacturing flexibility. However, a reduced process responsibility can demise the other factors when a critical level (X_1) of modular (out-) sourcing is passed. As a result, the flexibility of the manufacturing system is not increased (PRO_01) or can even be decreased (PRO_02).

The curve PRO_02 reflects the Deltacar case: the negative effects of reduced process responsibility overruled the other four moderating factors (reduced complexity, reduced extent of vertical integration, process and product know-how, and less hierarchical coordination structures) at the critical level (X_1). In other words, the outsourcing of final assembly activities and corresponding transfer of process responsibility to the module suppliers resulted in a decrease of manufacturing flexibility and performance.

It should be noted that the critical level (X_1) of outsourcing depends on the organisational strategy and context. For instance, Alphacar reduced the extent of vertical integration for a specific SUV model to 10% without a loss of flexibility or performance. This strategy is successful for Alphacar that defined the production of certain modules (e.g. gearboxes, engines, brakes) and final assembly operations, as core activities. However, this extent of outsourcing may not be suitable for Etacar since it operates in a different organisational context. In comparison, Etacar is much larger than Alphacar and therefore is able to generate scale advantages in producing modules such as axles. In other words, the critical point of outsourcing (X_2) for Etacar is likely to be on the left side of (X_1) for Alphacar.

Some researchers (e.g. Arnold, 2000; Ramaswamy & Rowthorn, 2000) regard manufacturing as a commodity that can be outsourced to third parties without second thoughts. A typical statement could be read in the Harvard Business Review: “Does manufacturing matter: the short answer is not much, and that is a good thing (Ramaswamy & Rowthorn, 2000)”. Similarly, Arnolds (2000) claims that manufacturing is a non-differentiating activity that easily could be transferred and handled by other organisations. Furthermore, Arnold (2000) claims that the desired level of organisational development is towards a ‘de-materialised’ organisation in which suppliers are not only responsible for final assembly operations but also for coordination efforts between suppliers.

Clearly, these authors have not considered long-term consequences of outsourcing final assembly operations. As can be derived from the case studies, manufacturing operations are sources of competitive advantage and should not be outsourced to suppliers. Except for the Deltacar case, final assembly activities are performed by the OEMs that have fully process responsibility. It should be noted that Deltacar has drawn the learnings from the concept as described in this study and is not pursuing this in the future.

Empirical research conducted by Pfeffer & Sutton (2000) and Bengtsson (2001) support the findings in this study and state that manufacturing operations incorporate a strategic potential that is often disregarded. In valuing the effects of outsourcing manufacturing activities, the long-term role of the organisational competitive advantage should be observed instead of short-term cost focus only. In alignment with the ‘resource-based view of the firm’ it can be concluded that final assembly activities should be internally performed since this can be a source of competitive advantage.

The integration of module suppliers in the production process should not be an end in itself. Even though OEMs are experimenting with new open assembly line architectures and supplier integration, this can maximally enhances the logistical flexibility of the manufacturing system. Other manufacturing related areas such as process flexibility, volume flexibility, expansion flexibility, product flexibility, machine flexibility and personnel flexibility offer similar potential for improving the manufacturing system.

7.3.3 Differentiation strategy

All four OEMs observed primarily pursue a differentiation strategy in order to gain a competitive advantage. In other words, these OEMs try to gain a competitive advantage by increasing the perceived value of the vehicles models offered. Attempts to create differences in perceived value of a product usually are made by altering the objective properties of the product.

As described in chapter 2, a variety of actions can be taken to influence customer perceptions. The use of a modular product structure facilitates the differentiation efforts and enables the variety to be increased at acceptable costs. Furthermore, the timing of market introduction can help in the differentiation efforts. When the Renault Megane was introduced in the beginning of the 1990's, a new market for multi-purpose vehicles had been created. The first mover advantage could be fully exploited and resulted in a large share of market in the first years. Furthermore, the first mover advantage additionally creates the perception that the products are more valuable (Lieberman & Montgomery, 1988). This would explain why customers perceived the quality of this model the highest as compared to competitor models introduced at a later point in time.

Reputation is one of the most powerful bases of the product differentiation. For instance, Opel / Vauxhall has a poor image and is associated with low quality. Even though vehicle quality and driving performance have been improved tremendously, changing this reputation remains difficult. On the other hand, premium brands that face quality problems (such as the Mercedes A-class initially) seem unaffected. So-called 'optimal reputation cheating' models (Rogerson, 1983; Allen, 1984) explain why these differences in perception continue to exits. These models describe the amount of reduced quality and performance that an organisation with a premium reputation can engage in without significantly reducing or damaging their image. One outcome of such models is that performing at lower levels than the customers expect, apparently maximises the economic performance. However, these arguments may work well in abstract mathematical models, it can be disastrous for 'real' organisations. If the actual performance of an organisation is less than the expected performance, the risk remains that in the long-term the reputation will be reduced. Moreover, a negative product reputation can be a source of competitive disadvantage, as was described for Opel / Vauxhall, even if the quality of the products is the same as, or even better, than the quality of other OEMs.

Product customisation is a basis for differentiation strategies that is enhanced by the use of modular product architectures. However, it is questionable to what extent customisation (build-to-order) strategies are feasible for OEMs. Moreover, counteracting the reduction of locked-in capital cost in a build-to-order strategy stand higher inventories of modules that are necessary to satisfy customer wishes that in turn have negative cost effects as well (Agrawal *et al.*, 2001). For example, in the middle of the 1980's Volkswagen strived to increase product variety. Initially, Volkswagen seemed well on its way to achieve these goals since they reduced the new-product-development time and could offer customers a wide range of options for each model. However, in the beginning of 1990's Volkswagen observed a tremendous increase in production costs and had to abandon the effort. Research had indicated that 20% of the product varieties accounted for 80% of the sales. As a result, Volkswagen launched the Touran[45] with a limited number of engines and model lines. Furthermore, only a limited number of customisable options are offered and the most common options are standardised as part of the model lines. This approach significantly reduced complexity and related costs.

In addition, Lampel & Mintzberg (1996) argue that standardisation (mass production process choice) and pure customisation (single unit process choice) are not polarising per se. Instead, they state that a combination of these strategies is feasible and depends on the customers an OEM chooses to serve. For example, Volkswagen offers more customisable options for the premium models (e.g. Phaeton, Passat) whereas a standardisation strategy is maintained for lower segments models (e.g. Lupo, Polo). It should be noted that customisation should begin with the activities closest to the market and can then spread 'upstream' in the value chain because of the related costs. For instance, the costs of customised services are much lower than for a customised vehicle design.

A differentiation strategy can help neutralise or diminish the effects from the environmental turbulence. As described in chapter 2, this strategy not only allows a reduction of the threat of new entrants, rivalry, and substitutes, it also reduces the threat of the power of module suppliers. An increase in the prices of modules, because of the dependence of OEMs on the module suppliers, may not affect the profitability of the OEM. Especially Porsche, DaimlerChrysler, and BMW have a relatively large loyal customer base, which is likely to accept the increased costs. Of course, the ability of the OEM to sell differentiated products to be somewhat immune from powerful module suppliers may actually encourage these suppliers to exercise their power. However, at some point, even the most loyal customers may find the prices too high. Any increase in prices beyond these barriers results in reduced economic profits for the OEMs. It should be noted that at these prices and supply-cost levels, OEMs may find it possible to obtain substitute suppliers, or other suppliers may have entered into a particular supply market (see paragraph 7.3.6). The existence of substitute suppliers or more suppliers for a specific component or module enables the OEM to maintain positive economic profits.

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[45] The Touran is a multi purpose vehicle based on the Golf (A0) –platform.

The ability of the differentiation strategy to add value for the OEM must be linked with rare and costly-to-imitate organisational strengths and weaknesses in order to generate a sustainable competitive advantage. The concept of product differentiation generally assumes that the number of organisations that have been able to differentiate their products in a particular way is, at some point in time, less than the number of organisations needed to generate perfect competitive dynamics (Calton & Perloff, 1994). When Chamberlin (1933) and Robinson (1934) described that highly differentiated organisations can charge a higher price for their products than the average total costs, they asserted that these organisations implement a rare competitive strategy. In the end, however, the rareness of a differentiation strategy depends on the ability of the organisation to be creative. In other words, differentiation is an expression of the creativity of individuals and groups within an organisation. Differentiation is only limited by the opportunity that exists in a particular industry and by the willingness and ability to creatively explore ways to take advantage of these opportunities.

Selling differentiated products often reveals the basis for product differentiation. However such bases vary in the extent to which they are easy to duplicate and are therefore subject to imitation. Difficult and costly to duplicate bases of competitive advantage build on history, uncertainty, and socially complex resources and capabilities (Barney, 2001). Even though many OEMs spend a tremendous amount of effort in trying to differentiate their products on the basis of product features, they are in most cases easy-to-duplicate. For example, competing firms are often the first ones to buy a new vehicle model that is launched in order to take it apart to discover the features that act as a basis of differentiation. This allows competing organisations to reverse-engineer vehicle features for own models. In the same way, product customisation is often easy-to-duplicate as well.

However, sometimes the ability of an organisation to customise products depends on the close relationship it has developed with customers. This type of customisation depends on the willingness of an organisation to share proprietary details about its operations, product, research and development, or other characteristics with module suppliers. This willingness in turn depends on the ability of each organisation to trust and rely on each other. On the one hand, the OEM must trust its module supplier that it will not reveal this information to competitors. On the other hand, the supplier must trust the OEM that they will not take unfair advantage by requiring the development of modules that has no other potential customers and then insist on lower than agreed prices (Barney & Hansen, 1994). If an OEM and module supplier have developed such socially complex relationships, and few other organisations have them, then these links with other organisations will be costly to duplicate and be a source of sustainable competitive advantage.

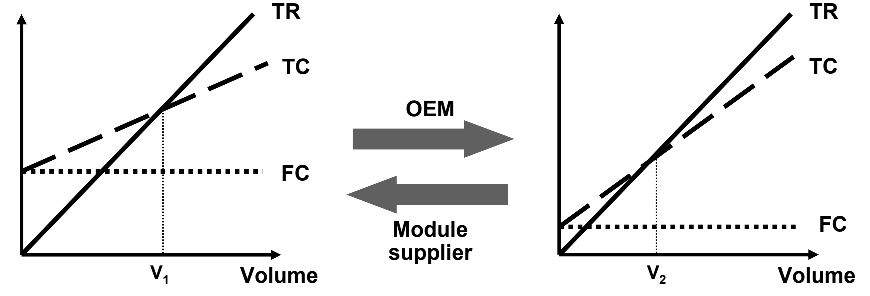
Even though other bases for product differentiation such as location, timing, distribution channels, service and support are all difficult to copy, the reputation of an organisation is considered as the most difficult to duplicate (Barney, 2001). A reputation is a socially complex relationship between an organisation and its customers, based on years of experience, commitment, and trust. Reputations can only be developed over time by consistent investment in this relationship.

7.3.4 Cost and asset reduction

As described in 2.3.2, in the mature automotive industry the basis for competitive advantage is likely to shift towards a focus on costs. As can be derived from the case studies, all OEMs focus on cost and asset reduction in order to increase profitability and shareholder value.

Modular sourcing is primarily applied to substitute fixed costs for variable costs. This is important for a differentiation strategy (in which a larger variety of products are offered in smaller volumes), since a break-even point can be reached faster than in traditional strategies (see figure 7-5)[46].

Figure 7-5: Shifting of cost



TR = Total revenues, TC = Total costs, FC = Fixed costs, $V_1 > V_2$

In the leftwards situation depicted, the OEM faces a relatively high level of fixed costs which are primarily incurred by development costs. When modular

[46] For the reasons of simplification, the constant costs are substituted by variable costs without affecting the total cost of the product at a given production volume.

sourcing is applied the development costs are transferred to the module supplier, which initially reduces the level of fixed costs. On the other hand, the variable costs increase since the modules need to be bought from the supplier. As a result, the fixed costs are substituted by higher variable costs (rightward situation) and enable OEMs to reach a break-even-point at lower volumes. It should be noted that a module supplier moves from rightward situation depicted to the left since orders from multiple OEMs can be aggregated. For this reason, module suppliers are able to generate scale cost advantages and reduce the average cost per unit.

The application of modular sourcing transfers the negative effects of the complexity trap (as described in paragraph 2.3.2) from the OEM to the module supplier. The higher overhead costs of the increased variety are only becoming apparent after a certain time period. Since the suppliers develop the modules for the increased variety, they face the negative cost effects. This also explains why after the development of a module, the supplier is often confronted with higher actual costs. Therefore, it can be concluded that from a supply chain perspective no effort is undertaken to reduce complexity and increase efficiency. Instead, only local optimisation is pursued.

Even though all four observed OEMs try to reduce their costs as much as possible, they do not follow a cost leadership strategy as described by Porter (1980). The aim to reduce costs is part of improving the operational effectiveness in which an optimal mix between costs and returns is sought. Porter (1996) argues that often researchers fail to distinguish between operational effectiveness and strategy. Operational effectiveness, necessary but not sufficient, is defined as performing similar activities better than competitors, whereas strategy refers to performing different activities, or the same activities in different ways, from one’s competitor. In accordance with Porter (1996) it can be stated that operational efficiency is often not sufficient for OEMs since the productivity curve is constantly shifting outward due to technological innovation. Consequently, continuing to outperform competitors requires constant improvements in operational efficiency in order to remain ahead of the productivity curve. Given that imitation of modular sourcing applications leads to the rapid diffusion of generic solutions this is quite difficult. Therefore, the basis for sustainable competitive advantage for OEMs can be found in the differentiation strategy as described in the previous paragraph.

Only the observed co-suppliers primarily pursue a cost leadership strategy. However, since all co-suppliers follow such a strategy, or if no co-supplier is facing cost disadvantages in imitating a cost leadership strategy, then being a cost leader does not generate a sustainable competitive advantage for these co-suppliers. Porter (1985) argues that value of a cost leadership competitive strategy to generate sustainable competitive advantage, depends on the particular strategy being rare and costly to imitate. The rarity and duplicability of such a strategy depends on the source of that competitive advantage.

Observing the research results in chapter 5, it can be concluded that all four OEMs strive for economies of scale. However, these types of economies are relatively easy-to-duplicate strategies, since they do not build on organisational history, uncertainty, or socially complex resources. Therefore, these sources are not easy to 'protect' and are available to competitors. Barney (2001) suggest that only time economies of scale are not easy to duplicate when the efficient size of the operations is a significant percentage of the total demand. Similarly, diseconomies of scale will not be source of sustainable competitive advantage either. The use of contract manufacturers reflects the strategy of the OEMs to reduce the size of operations to become more efficient. For new vehicle lines it is expected that these create diseconomies of scale because of the increased complexity of the production program. Contract manufacturers in turn use these volumes and are able to create economies of scale. These contract manufacturers assemble different vehicle models for different OEMs and are able to use a single assembly line for all vehicles. For instance, the contract manufacturer Valmet (Finland) produces the Porsche Boxster model and for Saab the 93 convertible model on the same assembly line.

Learning curve economies may be costly to duplicate. Spence (1981) suggested that for learning curves to be a source of sustainable competitive advantage, the learning obtained must be proprietary. In the automotive industry the ability to learn from the final assembly activities may vary significantly. As described in the Deltacar case, no possibilities to learn were available for Deltacar, since they were not involved in the final assembly operations. In contrast, Alphacar, Betacar, and Etacar were able to learn from its operations and were able to rapidly move down the learning curve and retain cost advantages.

Production processes and technology applied build on historical, uncertain, and socially complex resources and capabilities and are costly to duplicate. Differential access to factors of production (such as machines and personnel) is more difficult to duplicate. When this differential access depends on the volume of production, then it can be argued that economies of scale can be a source of competitive advantage as well. In other words, only if the specific conditions as stated above apply, it is likely that economies of scale leading to differential access to production factors and processes, it will be a source of competitive advantage. Furthermore, OEMs with cost advantages rooted in socially complex resources incorporate cost saving in every aspect. In the case of Deltacar, the plant was not able to focus on improved quality and the reduction of operating costs, since multiple parties has responsibility and no joint team 'spirit' could be established.

7.3.5 Impact on the industry structure

After discussing the strategic level in the previous paragraphs, this paragraph focuses on the impact of technological change (caused by modular sourcing) on the (meso) industrial level.

Tushman & Anderson (1986) proposed that technological changes can either strengthen or destroy organisations and industrial structures, depending on whether the change stems from familiar or new technologies. In addition, Utterback & Suarez (1993) argued that the appearance of a dominant design shifts the advantages to organisations capable of developing process innovation and integration skills. Despite their contribution to a better understanding of organisational adaptability and flexibility, these publications do not observe the effects of standard interfaces that the application of modular sourcing brings along. The emergence of standard interfaces in a modular vehicle design does not lead to a concentration of the automotive industry (Billington & Fleming, 1998). In contrast, the automotive industry will become more fragmented and less vertically integrated.

Product innovation efforts are typically aimed at improving product functionality and satisfying customer preferences. As the industry reaches a mature status, the basis of competitive advantage shifts from product differentiation to a focus on costs and improvement of the manufacturing flexibility (see paragraphs 7.3.2, and 7.3.3). Once the superiority of the modular product structure was recognised, a design 'competition' was started. This competition is characterised by high market share volatility, higher margins, proprietary design, and a rapid succession of new products. Bijker & Pinch (1987) argued that this level of competition ends with the appearance of a new dominant design. This dominant design involves a synthesis of previously available technologies and a resolution of competing technology standard. After the settlement of a dominant module design, only incremental changes to the product are made, which the consumer may not even perceive (e.g. the use of different materials for the front-end module).

On the one hand, several researchers argue that the incremental technological change favours large, incumbent, and vertically integrated organisations (Abernathy & Utterback, 1978; Tushman & Anderson, 1986). Established organisations are generally thought to be favoured because of economies of scale in production. On the other hand, some studies have questioned the evolution of innovation (Abernathy & Clark, 1985; Henderson & Clark, 1990; Utterback & Suarez, 1993) and state that the incremental change may not inevitably favour larger, better-established organisations. Moreover, supply chains seem to fragment and the level of specialisation is increased during periods of incremental evolution. This is partly related to structural forces (e.g.

logistical design, process choice) but primarily depends on the use of modular product architectures in the vehicle design.

Modular product architectures allow the development of modules to be isolated through the definition of interfaces. In addition, the creativity of the suppliers in finding solutions is only restricted by these interfaces (see paragraph 5.6). This, in combination with a focus on the core activities by the OEMs increases market opportunities for suppliers. Since the interfaces are clearly defined prior to the development of a module, the motivation of vertically integrated organisations decreases. In other words, there is no value in the integration of different technologies by the OEM that would favour a vertical integration. This is reflected by a reduction of the extent of value adding activities by the OEMs. Since the 1990's the observed OEM (in average) have reduced the extent of internally performed value adding activities by 26%. As a result, modules and components that were proprietary can now be bought from specialised suppliers, who in turn are able to create economies of scale (paragraph 7.3.4).

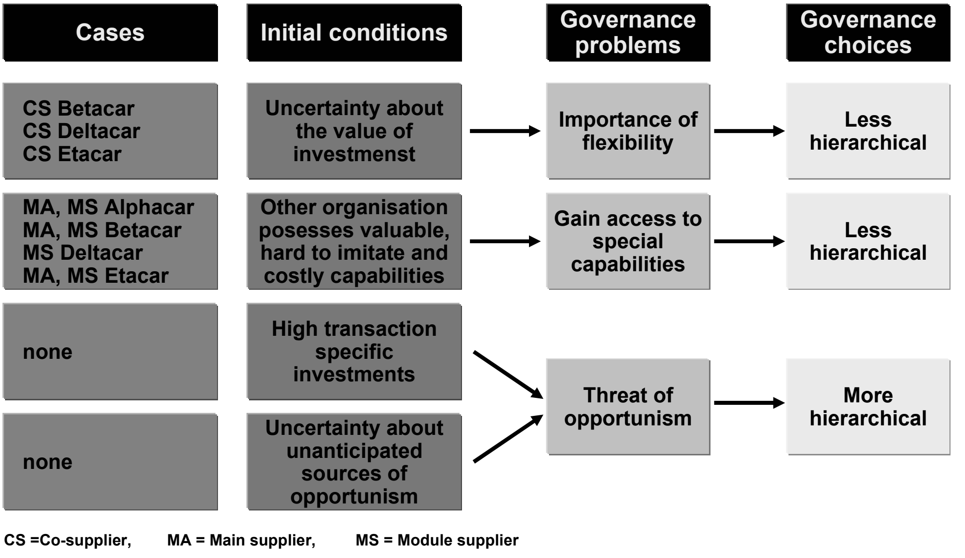
For electronics in a vehicle (e.g. engine control systems, navigation) standard interfaces are used in most cases (see paragraph 3.4.4). However, the use of standard interfaces in the design of a vehicle is avoided at all cost, even though this is theoretically possible. This 'plug-in' sharing of components (as applied in the computer industry) would severely threaten OEMs since vehicle components could theoretically be swapped between OEMs. This could for instance mean that a BMW vehicle framework can be used, with the interior of a Mercedes Benz and be equipped with an engine of Audi. Even though the fragmentation of the automotive industry activates new markets for suppliers, OEMs on the other hand need to be aware of these markets including threats and opportunities.

These findings contradict Tushman & Anderson (1986) and Utterback & Suarez (1993) who predict that maturity in industries and technological life cycle result in increasingly concentrated industries for suppliers. The use of product modularity and the definition of hard- and software interfaces change the automotive industry as can be observed today. BMW, DaimlerChrysler, Porsche, and Volkswagen face (like other OEMs) more fragmented supply chains and increasingly differentiated markets for modules.

7.3.6 Varying degrees of vertical integration

As can be derived in the case studies, all OEMs use market contracts to coordinate the relationship with the module suppliers. However, among the supplier types, different starting positions that justify the governance choices were identified. In figure 7-6 the suppliers observed in the case studies are categorised according to these different initial conditions and is based on the weighted model for governance decisions as developed by Barney (2001).

Figure 7-6: Cross-case comparison



In the discussion of modular sourcing, the interviewees associated 'module supplier' to a market contract-controlled relationship. Intermediary cooperation forms such as joint ventures are more common for R&D and were not regarded as typical sourcing relationships.

Among the interviewed specialists, it was generally understood that modular sourcing is primarily applied to reduce investments and complexity costs. The height and uncertainty concerning rate of return and payback-time of the investments made are the main reason to use less hierarchical coordination structures for co-supplier relationships. The OEMs want to remain flexible in the choice of the supplier. Consequently, a maximum contract length of one year is used in order to purchase non-complex components at the lowest cost possible. Often these non-complex components are purchased using Internet auctions.

For main and module suppliers market contracts are primarily to coordinate the relationship. These coordination structures are primarily chosen to gain access to a supplier's rare, valuable resources and capabilities despite the threat of opportunism. As one manager of Alphacar illustrated:

"… the threat of opportunism is minimised since suppliers do not want to risk their reputation as a trustworthy partner".

In other words, most suppliers have a competitive advantage in the development of modules, yet can be replaced by others if necessary. Therefore, adverse behaviour of any supply chain party results in contractual consequences and changes in market shares[47].

The transaction specificity of investments plays a primary role in the decision to outsource the development and production of core modules. For instance, the development and production of engines require extremely high transaction specific investments. Moreover, this is considered as core business of the OEMs in which a competitive advantage can be achieved and therefore is managed internally. The role of specificity of the investments has been confirmed by several empirical studies. MacDonald (1985) concluded that the greater the level of site specificity in an investment, the more likely this relationship is managed through a hierarchical governance. Furthermore, Armour & Teece (1980) and Masten *et al.* (1991) conclude that highly specific the human capital investments are likely to be coordinated in a hierarchy as well.

It should be noted that decisions concerning modular sourcing sometimes embodies a learning dilemma for OEMs. In some cases an extended co-operation could provide a broader base of competencies that cultivates learning and the creation of innovative solutions (Bengtsson, 2001). On the other hand, decision-making between core and peripheral activities is considered difficult among the OEMs observed. This is reflected by the differences among the OEMs as to what is developed and produced by module suppliers.

Observing figure 7-6 it can be concluded that initial conditions that are based on the transaction costs theory were not considered primer in the choice of the governance structure. It will be argued that this is caused by the uncertainty concerning technology. Furthermore, it will be suggested that the initial conditions of the framework as developed by Barney (2001) need to be substituted by: (1) the less it is expected that a technological change will influence the organisation, the less hierarchical relationships are chosen, and (2) the more it is expected that a technological change will influence the organisation the more this will lead to more hierarchical relationships. As described in paragraph 5.7, Alphacar, Betacar, Deltacar and Etacar favour short-term market contracts when uncertainty exists on technological standards in the industry. This prevents the OEMs from being 'locked-in' and avoids getting in a disadvantageous competitive position by investing in the wrong technology.

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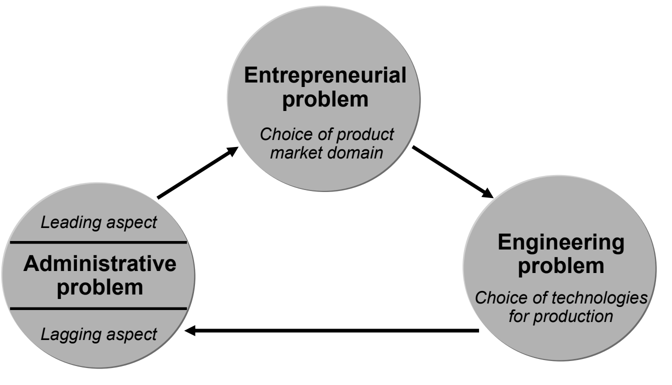
[47] This cause-and-effect only applies to oligopoly market situations.

From a contingency theory point of view, Miles & Snow (1978) argued that when the environment is changing, it is necessary to adjust the organisation accordingly. They argue that organisational survival depends on the quality of the 'fit' which managers achieve among variables such as product-market domain, its technology for serving that domain, and organisational structures and processes developed to coordinate and control the technology. Miles & Snow (1978) developed the so-called 'adaptive cycle', which illustrates the dependence of organisations on technology (see figure 7-7).

Figure 7-7: Adaptive cycle



The entrepreneurial problem deals with the development of new products and services to secure or gain market share. For instance, this addresses the need for updating the product market mix of an organisation. The engineering problem involves the creation of a system that puts the entrepreneurial problem into operation. The administrative problem deals with the reduction of uncertainty within the organisational system and refers to the rationalisation and stabilisation of those activities, which helped in solving challenges, faced by the organisation during the entrepreneurial and engineering phases. The administrative problem involves a duality since it also involves formulating and implementing those processes that will enable the organisation to continue to innovate. Thus the administrative problem thus balances two somewhat conflicting needs.

In the 'ideal OEM', management would be able to create an administrative system that smoothly directs and monitors the organisation's current activities, without allowing the system to become too rigid that would endanger future innovative activities. In other words, the administrative system is to be viewed as both lagging and leading variable in the process of adaptation (Miles & Snow, 1978). As a lagging (exploitation) variable, the administrative system must rationalise the strategic decisions made prior. On the one hand, the organisation needs to secure a synchronisation of transactions and assignment of tasks[48]. On the other hand, as a leading (exploration) variable the administrative system needs to facilitate or restrict the organisation's future capacity to adapt, depending on the extent to which the management formulates the paths along which such activity can proceed[49].

It should be noted that the technological uncertainty is viewed differently among the OEMs. For instance, because Betacar was involved in the development of a direct fuel injection system (see paragraph 5.6), it had a better feeling for the developments in this area than the other OEMs. Moreover, the perceived level of uncertainty plays an important role in this as well. While specifying the source of uncertainty identifies the domain of the environment, which the decision maker is uncertain about (e.g. competition, suppliers, technological development), specifying the type of uncertainty focuses on delineating the nature of the uncertainty being experienced.

The transaction costs theory argues that in order to secure a flexible situation a possible range of decision alternatives have to be available. Therefore short-term market contracts will prevent an organisation form being 'locked' into the 'wrong' technological solution. In other words, the less it is expected that a technological change will influence the organisation, the more likely it is that the organisation governs its operations through less hierarchical relationships. Similarly, the more it is expected that a technological change will influence the organisation will lead to more hierarchical relationships. Empirical studies by Flygansvær *et al.* (2002) and Dickson & Weaver (1997) confirm these arguments and state that closer forms of cooperation are likely to be chosen when manager perceive a high technological uncertainty.

When these two initial conditions would be observed in the framework of Barney (2001), it would be applicable for all observed suppliers in the case studies. This inclusion would explain why the transaction cost theory was considered a basic premise in governance decision-making among the interviewed managers, yet this was not reflected by the initial conditions in the original model of Barney (2001).

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[48] This can be secured best by centralised decision-making.

[49] This can be secured best by decentralised decision-making.

7.4 Evaluation of research design

In this study, the research design is based on both exploratory case studies and survey-based research. This mix enabled the combination of the strengths of each method as well as the integration of fieldwork and survey findings. Furthermore, this combination not only increases the accuracy of the study, but also allows the formulation of more conclusive findings since the applied methods lead to similar conclusions.

As discussed in chapter 4, case studies were used to investigate the relationship between modular sourcing and manufacturing flexibility. While conducting the case studies a huge volume of relevant data was collected. However, analysing this data and writing case study protocols proved to be very time-consuming. Furthermore, the instrumentation devised prior to the fieldwork facilitated the cross case comparison. The use of a checklist to gather similar data across cases proved to be very helpful.

In case studies, one does not generalise from samples to larger universes. Instead the generalisation is done from the results to some broader theory, which in turn is reflected by the conceptual model as developed in paragraph 4.2. Critics of case studies argue that the generalisability of their results is low because the evidence is based on a limited number of cases. However, such criticisms confuse analytical generalisation with statistical generalisation (Mitchell, 1983). Indeed, case studies are less suitable for statistical generalisation, that is, generalisation on the basis of a 'sampling logic'. Such logic assumes that the selected sample represents a larger pool of subjects. In contrast, the rational for case studies lies in their potential for 'analytic generalisation' in which a particular set of results are generalised to some broader theory.

A survey was included in this study to statistically generalise the findings of the case studies. The case study material and expert opinion interviews were very helpful to develop a survey that was focussed on the key relationships of the conceptual model. The survey confirmed a positive relationship between modular sourcing and the seven dimensions of manufacturing flexibility. The appropriate way of viewing this study is as a comparison between OEMs varying the degree of modular sourcing and the level of supplier integration. However, the cross-sectional nature of the survey precluded the detection of time-lag effects. These effects are related to the time delay between implementing a measure (application of modular sourcing) and the visible effect in the reduction of complexity related costs. The survey thus represents the description of the actual variables at the time of this study.

Finally, since this study is based on an extensive analysis of the micro economical level, bottom-up implications for the chosen business strategy and industry structure can be derived (see paragraph 7.3).

7.5 Implications & recommendations for research

This study contributes to the growing interest in achieving manufacturing flexibility through the application of modular sourcing. The development of a conceptual model that grasps the effects of modular sourcing on manufacturing flexibility is relevant quest for several reasons – as suggested in the introductory chapter. The presented conceptual framework provides insight in the interdependencies of an organisation's markets, the relevant complexity, the organisation of manufacturing activities, and the performance in terms of manufacturing flexibility. The explicit inclusion of several manufacturing flexibility dimensions and corresponding analysis of different supplier types tries to bridge the gap for understanding the relationship between modular sourcing and manufacturing flexibility. Future research may replicate and extent the findings of this study.

The developed conceptual framework is useful for other industries and countries.

Even though the developed conceptual framework has been developed from a German automotive background, the general model can serve to generate other specified models as well. This applies to different industries (e.g. computer hard- and software, consumer goods, pharmaceuticals), as well as different geographical locations. Naturally, the set of relevant factors may be different. Yet, the developed models will resemble each other, facilitating comparative industrial economic research.

The main research construct consists of the modular sourcing as well as seven manufacturing flexibility dimensions. In the development of the conceptual framework a trade-off had to be made between focus and inclusiveness. At the outset of this research, the call for a more interactive model by researchers such as Barney & Zajac (1994) that observe technological aspects and resources (including personnel), was heeded. This was considered important since the literature on modular sourcing makes many predictions that go across levels that traditionally have been studied in isolation, such as the product and logistical level.

Longitudinal studies are necessary for future research.

In this study the relationship between modular sourcing and manufacturing flexibility has been investigated with the use of case studies and a survey. This survey had a cross-sectional character resulting is a supportive relationship between these two research constructs. In order to verify a direct cause-and-effect relationship future research should involve a longitudinal survey, which allows the observation of time-lag effects.

The developed multi-item scale should be extended in future research.

The developed multi-item scale for measuring manufacturing flexibility will be of benefit for academics. These measures provide a basis for future empirical work since they can be transformed easily for the use in other industries (e.g. computer hard- and software, consumer goods, pharmaceuticals). Even though manufacturing flexibility has already gained a lot of attention in operations research, the relationship with other (more strategically) oriented flexibility dimensions such as marketing flexibility and R&D flexibility should be undertaken in the future. Accordingly, the scale items as developed in this study may need to be extended.

In future research, the role of product platforms needs to be observed as well.

The definition of product architectures determines how the corresponding platforms need to be designed. In the decomposition of a vehicle into modules, different approaches can be taken that in turn influence the definition of core modules. Worren *et al.* (2002) argue that the planning of future product platforms represents another critical process. Meyer & Seliger (1998) point out that it is often difficult to reconcile the desire to leverage current platform investments with the risk of becoming obsolete if the platform is not continuously renewed. This could be observed at Deltacar would refrained from renewing a certain product platform. Despite the initial euphoria of the use of platforms across several vehicle models, several negative effects have been coming about. Fisher *et al.* (1995) concluded that the establishment of product platforms can significant incur coordination costs between the different departments. Furthermore, the use of product platforms increases the level of 'cannibalisation' among vehicle models and brands since customers perceive vehicles as too similar.

7.6 Management implications & recommendations

In this paragraph the implications and recommendations for management are derived.

Outsourcing does not always improve manufacturing flexibility and performance.

The most important implication of this study for practitioners is that modular sourcing enhances the flexibility of the manufacturing system. However, managers that think that blindly increasing the extent of modular (out-) sourcing is the best approach to increase flexibility and reduce costs are doomed to fail.

The often-quoted champions of virtual organisations have urged managers to sub-contract everything that is possible. Because of these champions, we have come to believe that an organisation that invests as little as possible will be more responsive in a turbulent environment and is more likely to obtain a competitive advantage. After studying four successful German OEMs, it can be concluded that the benefits of outsourcing final assembly activities have been overstated in the literature. Moreover, this study provides evidence that in the automotive industry manufacturing operations are a source of competitive advantage and should not be outsourced to suppliers. Instead of focussing on short term cost reductions by means of outsourcing, managers should observe the long-term effects on the competitive position.

OEMs with sufficient development capabilities have a favourable long-term competitive position.

Organisations with extensive development and production capabilities prosper as dominant players in a supply network. Because DaimlerChrysler and Volkswagen are much larger than its suppliers, and are large customers of the suppliers, they can compel those suppliers to make changes in their business processes. In a more egalitarian network, suppliers can demand a large share of the economic benefits of innovations, using so-called ‘hold-up’ strategies. OEMs with sufficient development and production capabilities such as DaimlerChrysler and Volkswagen are not very vulnerable to such tactics and thus are in a better position to drive and coordinate systematic innovation. Smaller organisations that merely control and coordinate the advance of technologies (for instance ‘virtual’ organisations) do not have such a favourable long-term competitive position.

In addition, OEMs must continue to develop critical parts of the vehicle internally and form strategic alliances with multiple module suppliers. Although networks may be effective in the short-term for an unchanging technology, they will not adept over the long-term as technology develops and organisations must depend on internal capabilities to keep up. The euphoria of networked organisations and decentralisation arises, from the observation over a time horizon that is far too short. All leading German OEMs make extensive investments to enhance their current capabilities and stimulate the creation of new ones. Exactly because many innovations are systematic, outsourcing without strategic leverage and coordination is the wrong strategy to follow. In other words, key development activities must be conducted in-house to capture the rewards from long-term R&D investments. Without directed coordination, the complementary innovation required to leverage new technology may not be forthcoming.

Open architecture assembly plants are not the only way to improve manufacturing flexibility and performance.

Volkswagen was one of the first to apply open architecture assembly lines at plants in Resende (Brazil), Mlada Boleslav (Chez Republic), Mosel (Germany), Matorell (Spanien), and Setubal (Portugal). Furthermore, DaimlerChrysler applied this at plants in: Curitiba (Brazil), and Hambach (France); Porsche and BMW in Leipzig (Germany); General Motors in Macaw (Brazil), Rüsselsheim (Germany), and Rio Grande Sur Mer (Brazil). Suppliers such as Delphi have been experimenting with greenfield open architecture plants as well for instance in Alabama (United States). It is important to observe that blindly implementing a ‘me-too’ strategy does not result in a sustainable competitive advantage.

The integration of module suppliers in the manufacturing facilities should not be an end-in-itself. Even though open architecture supply chain designs are praised in the literature as state-of-the-art and innovate, organisations can maximally enhance their logistical flexibility. Other areas such as processes, volume, expansion, product, machines and personnel offer similar potentials for enhancements, yet are often neglected. In other words, there are several equally goods ways to improve the flexibility of the manufacturing system. It is important that the mix of these flexibility dimensions is in alignment with the organisational strategy. Even though open architecture assembly plants enhance the logistical flexibility, this does not automatically imply that (older) existing plant are principally less flexible. Many of these new approaches still have to prove that they truly can increase the flexibility and performance.

Finally, manufacturing systems need to continuously increase the variety and speed of the capabilities as well as the responsive to changes. Unfortunately, most managers try only to copy other approaches without observing internal competencies and structures. Consequently, these manufacturing systems are at best able to achieve similar performance levels but are unlikely to outperform their competitors. The developed conceptual model in this study may provide managers a useful guide in discovering multiple leverages for improving the flexibility of the manufacturing system and design future manufacturing system in a more flexible manner.

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Appendix A: Overview of OEM consolidation

Figure: Consolidation of OEMs over the years (source: BMW AG and added)

Appendix B: Transaction costs determinants and structure

Williamson (1975) distinguishes several cost drivers (environmental factors, human factors and transaction conditions) that determine the height of the transaction costs and influence governance choices.

Environmental factors

The environmental factors as described by Williamson (1975) are primarily determined by insecurities in prognoses and the number of potential contract partners. First of all, the insecurity of prognoses is enlarged as a result of the increasing turbulence and complexity in the environment. Williamson (1975) describes this as the problem of completely specifying a decision tree. In addition, Koopmans (1957) distinguishes between primary insecurities that refer to unpredictable changes and secondary insecurities, which arise because of insufficient communication between the transaction parties. Secondary insecurities are reflected by fast changing prices, amounts, demands, technical specifications or political changes that cannot be forecasted (Riordan, 1984). Second, the number of potential contract partners determines the impact of the environment as well. If the number of these partners is limited, the risk of opportunistic behaviour is increased since the danger of terminating the relationship is low. However, in a 'large bidding situation' the risk of opportunistic behaviour is not present because of the competition among the potential contractors (Williamson, 1975). A large bidding situation can evolve into a small number situation if contracts are prolonged over time. Williamson (1975) describes this as a fundamental transformation and states:

> *"… what was a large bidding condition at the outset is effectively transformed into one of bilateral supply thereafter… (Williamson, 1975, p. 61)"*

In other words, the initial high number of transaction partners is substituted by fewer relationships that need to be managed. However, in the latter mentioned situation the parties are highly depended on each other.

Human factors

The human factors refer to the imperfections of the human being in decisive situations. Williamson (1975) argues that an individual is 'bounded rational' and under specific circumstances can behave opportunistic. This 'bounded rationality' comprises the limited capabilities of the human being and contradicts the 'homo oeconomicus' view on the individuals by neo-classical economics. In addition, Moerman (1999) states that in day-to-day management most decisions are based on emotions rather than ratio. In his book 'vom Kriege' von Clausewitz (1832) described that most real events in a society are driven by:

> *"… incomprehensible forces like change, emotion, bureaucratic irrationalities, politics and a great many strategic decisions are made unconsciously… (von Clausewitz, 1832)"*

Traditional economic theorists were criticised for the lack of human involvement in their approaches. For instance, the neo-liberal Röpke (1963) criticises the economic theory of Keynes in his publication 'The economics of a free society':

> *"… the economic system (as Keynes describes it) is a part of a mathematical and mechanical universe, with economic activity being the product of quantifiable aggregates such as consumption and investments, instead of a result of actions by individuals… Keynes took the human out of the human actions and reduced the economic system to a machine…(Röpke, 1963)"*

Opportunistic behaviour is displayed when one party lets its own interest prevail at the costs of others. This phenomenon is likely to occur within organisations in which performance is unrelated to payment. In this situation, it is very likely that an individual does not perform 100%, which referred to as a 'shirking problem' (Alchian & Demsetz, 1972). In addition, Williamson (1975, 1985) extends the principle of own profit maximisation from Adam Smith and stated that:

> *"Opportunism extends the conventional assumption that economic agents are guided by considerations of self-interest to make allowance for strategic behaviour (Williamson, 1975, p. 26)…. opportunism refers to the incomplete or distorted disclosure of information, especially to calculate the efforts to mislead, distort, disguise, obfuscate, or otherwise confuse (Williamson, 1985, p. 47)."*

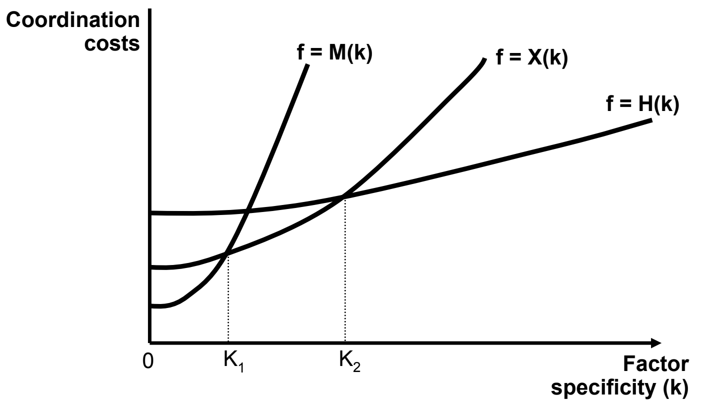
Opportunistic behaviour includes a strategically planned line of actions with the use of tricks ('self seeking interest with guile'), deceit, distortion and manipulation of data (Sauter, 1985; Vosselman, 1995). These forms especially occur in cases of information asymmetry between buyer and supplier.

<u>Transaction conditions</u>

As a third factor of influence on the height of the transaction costs, Williamson (1975) mentions the transaction conditions 'frequency' and the 'specificity'. The influence of the transaction 'frequency' on the transaction costs is relatively straightforward. Transaction costs (e.g. machine set-up costs) can be amortised much faster when the frequency of the transactions is increased. When a specific effort is interesting for only a few potential contractors and the alternative use of investments is limited, the transaction can be defined as ‘asset specific’ (Williamson, 1975)[50]. Based on empirical research conducted by Benjamin *et al.* (1986) and Bauer (1990) several forms of specificity can be distinguished.

The (1) ‘site’ specificity refers to location of the transaction, whereas the (2) ‘physical asset’ specificity refers to specific adjustments of resources (e.g. machines) without an alternative use. The (3) ‘human asset’ specificity deals with the specific knowledge and experience of the personnel employed and primarily influences the mobility of personnel flexibility (see chapter 3). The (4) ‘dedicated assets’ observe the contract specific production capacity largely influences the mobility of expansion and volume flexibility. Finally, (5) time specific investments refer to committed resources for a certain period of time. In the figure below, the factor specificity is plotted against the coordination costs in order to determine the effects of the specificity on the governance choices.

Figure: Hybrid forms in dependence of factor specificity



[50] The most popular example for the consequences of assets specificity has been the relationship between General Motors and Fisher Body between 1919 and 1926. After a 10 year contractual agreement was concluded in 1919, GM's demand for closed-body cars increased to extent that it became unhappy with the contractual price provisions and ‘urged’ Fisher to locate its body plants adjacent to GM assembly plants, thereby to realise transportation and inventory economies. Finally, Fisher Body was merged into GM in 1926 after Fisher had resisted GM's locational demands. The GM officials argued that the main reason for the acquisition was to make sure that the body plants were located next to General Motors assembly plants (Williamson, 1975).

If the cost of governance for hierarchy (H), hybrid form (X), and market (M) are understood as a function of the factor specificity the following is valid: M(0) < X(0) < H(0) and $M^I < X^I < H^I$ (Wolters, 1995). It should be noted that this is only valid under the assumption of comparable factor specificity. When the factor specificity varies, markets with little specific investments are efficient at the interval $[0, K_1]$. Hybrid forms are efficient at the interval $[K_1, K_2]$ and hierarchies are efficient at the interval $[K_2, \rightarrow]$.

In general can be stated that the opportunity costs[51] are low for specific transactions and rise when the specificity is reduced (Schumann, 1987). If specific investments are made that generate additional profit in comparison to the best next alternative then this is referred to as 'quasi rents':

> *"… the quasi rent value of the asset is the excess of its value over its salvage value, that is, its value in its next best use to another renter… (Klein et al.,1978, p. 298)"*

In the effort of transaction partners to appropriate rents, the mutual dependence is likely to increase, which is referred to as being 'locked-in' (Williamson, 1979; Katz, 1989; Wolters, 1995). For instance, if a supplier has invested in specific production capacity, the OEM could renegotiate prices for the products delivered when the supplier cannot alternatively use this capacity[52]. On the other hand, the supplier can exploit the dependence of the OEM as well. Especially shortly before the launch of a new vehicle model, the supplier could renegotiate prices as well since the costs for switching to another supplier are high.

Governance choices

Williamson (1975) developed the 'organisational failures framework' in which the described influential factors on transaction costs and governance choices are related to each other (see figure below).

Based on this framework, Williamson (1975) argued that hierarchical governances are best suited for situations in which the uncertainty is relatively high and the number of potential transaction partners is low. In such situations the risk of opportunistic behaviour is high especially if the level of asset specificity is substantial. This contemplation is referred to as 'information impactedness' (Williamson, 1975). Moreover, in hierarchical governance structures the

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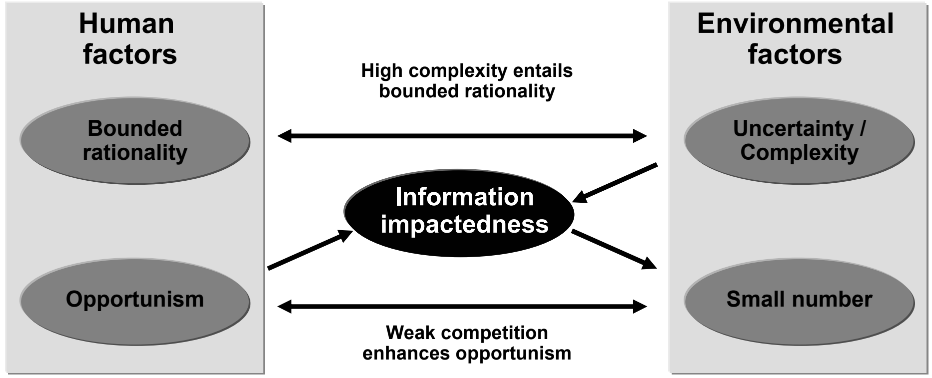
[51] This refers to the costs for not using the best possible alternative (see Bulte *et al.*, 1995).

[52] If for whatever reason the contract is terminated, factor specific investments can be considered as 'sunk costs' (Wieandt, 1994).

information asymmetry is reduced which allows a better control of primary and secondary insecurities. On the other hand, if ‘efforts’ can be clearly defined in a contract and only low levels of opportunism exists, market contracts are the most efficient coordination mechanisms (Ouchi, 1980).

Figure: Organisational failure framework



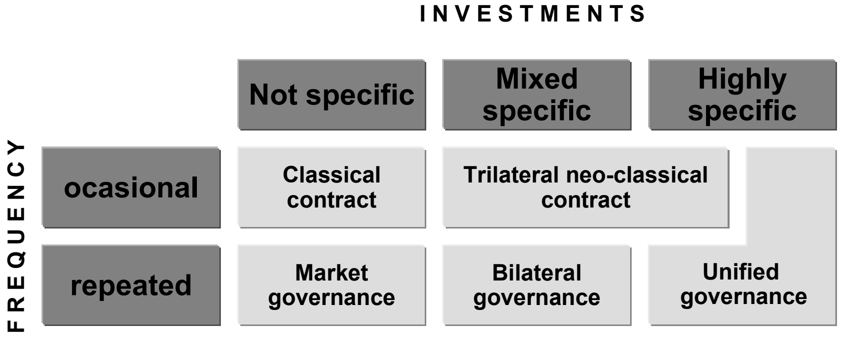
In the mid 1980’s intermediary coordination forms appeared and, as a result, were included in the transaction costs theory.

> *“… hybrids are no more than discrete structures on a sliding scale between spot market contracts and fully fledged formal organisations…(Hutter & Teubner, 1993)”*

Williamson (1985) rudimentarily described different hybrid coordination forms that were based on the contract typology of MacNeil (1978). These hybrid forms are referred to as ‘trilateral governance structures’ (see figure below).

Furthermore, Williamson (1985) suggested the use of ‘trilateral neo-classical contract’ when the asset specificity is mixed or high. In such governances, a third party (referee) decides in the case of conflict. When the frequency of the transactions is increased ‘relational contracts’ should be used in which the mutual obligations are permanently administrated. A classical contract or market governance structure should be chosen if the investments are not specific. When the frequency of the transaction is increased the classical contract reaches the boundaries and market governance structures should be chosen.

Figure: Contract typology



In bilateral governances, the legal independence of both parties is guaranteed and enables the coordination of mixed specific transactions that occur frequently. This two-way system is determined by conditions (credible commitments) that form securities (hostages)[53], which ensure an adequate execution of the contract (Williamson 1983; Schumann, 1987). Finally, highly specific transactions can be controlled best either within unified governances or in a trilateral neo-classical contract depending on the frequency of the transaction.

[53] Therefore, this situation is often referred to as a 'hostage construction'.

Appendix C: Items used for survey-based research

Items for process flexibility

ITEM	DESCRIPTION	SOURCE(S)
PRC_01	The production flow can be re-routed to parallel assembly lines	Rieken (1995)
PRC_02	The manufacturing system is fully functional when some machines are not operative	Carter (1986)
PRC_03	The manufacturing system has many alternative routing paths under failure conditions	Proposed
PRC_04	Many machines are linked by the material handling system	Gupta & Somers (1996)
PRC_05	A large number of product categories are produced in the manufacturing system	Suarez *et al.* (1995)
PRC_06	The manufacturing system can quickly changeover to a different product mix	Dixon (1992)
PRC_07	The choice of processing operations does not affect the quality of the output	Proposed
PRC_08	The choice of processing operations does not affect the production costs	Proposed

Items for volume flexibility

ITEM	DESCRIPTION	SOURCE(S)
VOL_01	The manufacturing system can handle rapidly increasing production volumes	Proposed
VOL_02	The output volumes for the different products can be varied largely	Koste (1999)
VOL_03	The level of production volume can be changed quickly	Gerwin (1993)
VOL_04	Volume changes can be handled easily	Proposed
VOL_05	The manufacturing system can operate profitably at different production volumes	Sethi & Sethi (1990); Gupta & Somers (1996)
VOL_06	The quality of the goods produced is not affected by changes in volume	Proposed

VOL_07	The productivity of the manufacturing system is not affected by changes in volume	Proposed
VOL_08	Process improvements can be introduced to the manufacturing system without creating disturbances	Proposed

Items for expansion flexibility

ITEM	DESCRIPTION	SOURCE(S)
EXP_01	A large number of equipment additions to the manufacturing system can be made	Koste (1999)
EXP_02	Process improvements can be introduced in the manufacturing system	Sethi & Sethi (1990); Gupta & Somers (1996)
EXP_03	The manufacturing system can be expanded easily when needed in the long-term	Gupta & Sommer (1996); Sethi & Sethi (1990)
EXP_04	Manufacturing system expansions do not affect the quality levels of the output	Koste (1999)
EXP_05	Manufacturing system expansions do not affect the throughput time	Proposed

Items for logistical flexibility

ITEM	DESCRIPTION	SOURCE(S)
LOG_01	The production system can handle many different delivery sequences	Proposed
LOG_02	The variety of JIT delivery sequences is high	Proposed
LOG_03	The computer-supported quality control of incoming goods reduces flow interruptions	Pieper (1995)
LOG_04	The cost for changes in inbound and outbound logistic is low	Proposed
LOG_05	Disturbances in delivery times and sequences do not affect the quality of the products	Proposed

Items for product flexibility

ITEM	DESCRIPTION	SOURCE(S)
PRO_01	A large number of new or modified products are introduced each year	Gupta & Somers (1996)
PRO_02	The product configuration can be changed many times during the manufacturing process to accommodate to customer preferences	Proposed
PRO_03	Product development lead times are low because of a modular product structure	Gupta & Somers (1996)
PRO_04	The variety of modules / components used allow many different products to be configured	Proposed
PRO_05	The time required to change to a different product mix is short	Upton (1995)
PRO_06	The performance of the manufacturing system is not affected by a change in product design	Proposed
PRO_07	Quality levels of the output are not affected by changing the product mix	Proposed

Items for machine flexibility

ITEM	DESCRIPTION	SOURCE(S)
MAF_01	The number of different operations a typical machine can perform is high	Carter (1986); Gupta & Somers (1996)
MAF_02	Machines can be re-programmed easily to take over different tasks	Proposed
MAF_03	Machine re-tooling times are short	Zäpfel (1982)
MAF_04	Machines can perform different types of processing or assembly operations	Carter (1986); Barad (1992)
MAF_05	Machine changeovers between operations are not expensive	Carter (1986)
MAF_06	All machines achieve similar performance across all operations	Koste (1999)
MAF_07	The processing time of an operation is not affected by machines choice	Benjaafar (1994)
MAF_08	All machines are equally reliable for all operations	Chandra & Tombak (1992)
MAF_09	Switching from one operation to the next does not require much effort	Chandra & Tombak (1992)
MAF_10	Machines can perform operations which differ greatly from one another	Hyun & Ahn (1992); Koste (1999)

Items for personnel flexibility

ITEM	DESCRIPTION	SOURCE(S)
PER_01	Many job classifications exist in the workforce	Cox (1989)
PER_02	Employees can perform many different types of tasks	Chen *et al.* (1992)
PER_03	The number of tasks and employees can easily be varied	Proposed
PER_04	A short time-delay occurs when employees are moved between different tasks	Malhotra *et al.* (1993)
PER_05	Employees achieve similar performance levels for all tasks	Proposed
PER_06	Employees are equally efficient in all tasks	Bobrowski & Park (1993)

Items for modular sourcing

ITEM	DESCRIPTION	SOURCE(S)
MOD_01	In a modular sourcing relationship the OEM highly depends on the module supplier	Wolters (1995)
MOD_02	In a modular sourcing relationship the intensity of cooperation is increased	Eicke & Femerling (1991); Wolters (1995)
MOD_03	In a modular sourcing relationship the mutual dependence is high	Eicke & Femerling (1991)
MOD_04	In a modular sourcing relationship the supplier needs to have a high level of problem solving ability	Eicke & Femerling (1991); Wolters (1995); Piller & Waringer (1999)

Appendix D: Q-sorted Test

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Department of Marketing & Organisation
Coordinators: **Prof. dr. J. Paauwe**
Prof. dr. H.R. Commandeur

Audi AG
Purchasing Department
Attn: Mr. Mustermann
D-85059 Ingolstadt

12th September, 2002

Dear Mr. Mustermann,

This study is aimed at developing a framework for measuring manufacturing flexibility that takes the effects of modular sourcing applications into account. This test has been developed in order to assess the quality of the proposed flexibility dimensions that comprise manufacturing flexibility.

In section 1 the flexibility dimensions are briefly described. In section 2 you will find items described that need to be valued. The goal of this test is to match these listed items with the associated flexibility dimension.

Please read the descriptions carefully and then record the 'letter' of the given flexibility dimension you feel is most closely associated with the particular item. You may refer to the definitions in section 1 as often as you like.

After completing this questionnaire, please return it to the address above. Thank you in advance for your participation.

Kind regards,

Peter Miltenburg

Section 1: Flexibility dimensions

Process flexibility relates to the number of products that have alternate processing plans and the variety (heterogeneity) of processing operations used without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Expansion flexibility corresponds to the ability of a manufacturing system to accommodate a number and a variety of expansions without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Logistical flexibility corresponds to the ability to control and execute a number of logistical tasks both inbound and outbound with a large variety without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Product flexibility corresponds to the number and heterogeneity of newly introduced products or modifications on existing products that are achieved without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Volume flexibility corresponds to the ability of a manufacturing system to be operated profitably (in the short-term) with a various amount of volume for several products without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Machine flexibility corresponds to the number of operations and the variety of products that can be produced with the use of a machine without incurring negative effects (e.g. time-delays, changes in performance outcomes) when switching from one operation to another.

Personnel flexibility corresponds to the ability to adjust the number of employees and tasks, including the variety of tasks (heterogeneity), without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Section 2: Items for valuation

DIMEN-SION	ITEMS (EXAMPLE)
B	The manufacturing system can be expanded when needed in the long-term
D	The performance of the manufacturing system is minimally affected by a change in product mix or a modification because of a modular product structure

(scores of n=10)	ITEMS
9	All machines are equally reliable for all operations
9	A large number of new or modified products are introduced each year
9	The product configuration can be changed many times during the manufacturing process to accommodate to customer preferences
10	Machine changeovers between operations are not expensive
9	All machines achieve similar performance across all operations
8	The time required to change to a different product mix is short
9	Machines can perform different types of processing or assembly operations
9	The productivity of the manufacturing system is not affected by changes in volume
10	Process improvements can be introduced to the manufacturing system without creating disturbances
9	The processing time of an operation is not affected by machines choice
9	The manufacturing system can handle rapidly increasing production volumes
9	Quality levels of the output are not affected by changing the product mix
9	Volume changes can be handled easily
8	The manufacturing system can operate profitably at different production volumes
9	The quality of the goods produced is not affected by changes in volume
9	The performance of the manufacturing system is not affected by a change in product design
10	The production flow can be re-routed to parallel assembly lines
10	Employees achieve similar performance levels for all tasks
9	Many machines are linked by the material handling system
8	A large number of product categories are produced in the manufacturing system
10	Switching from one operation to the next does not require much effort
9	Product development lead times are low because of a modular product structure
9	The variety of modules / components used allow many different products to be configured
9	Many job classifications exist in the workforce
10	Employees can perform many different types of tasks
7	Process improvements can be introduced in the manufacturing system
10	The manufacturing system can be expanded easily when needed in the long-term

10	Machines can perform operations which differ greatly from one another
9	The output volumes for the different products can be varied largely
8	Disturbances in delivery times and sequences do not affect the quality of the products
9	The variety of JIT delivery sequences is high
9	The computer-supported quality control of incoming goods reduces flow interruptions
9	The level of production volume can be changed quickly
9	Employees are equally efficient in all tasks
9	The choice of processing operations does not affect the quality of the output
8	A large number of equipment additions to the manufacturing system can be made
9	The manufacturing system can quickly changeover to a different product mix
9	The choice of processing operations does not affect the cost of the product
9	The production system can handle many different delivery sequences
9	The cost for changes in inbound and outbound logistic is low
10	The number of tasks and employees can easily be varied
10	A short time-delay occurs when employees are moved between different tasks
10	The manufacturing system is fully functional when some machines are not operative
8	The manufacturing system has many alternative routing paths under failure conditions
10	The number of different operations a typical machine can perform is high
10	Machines can be re-programmed easily to take over different tasks
10	Machine re-tooling times are short
8	Manufacturing system expansions do not affect the quality levels of the output
8	Manufacturing system expansions do not affect the throughput time

Appendix E: Action taken as a result of the pre-test

CODE	ORIGINAL ITEM	ACTION
PRC_03	The manufacturing system has many alternative routing paths under failure conditions	Deleted (negative item-to-total correlation)
PRC_04	Many machines are linked by the material handling system	Deleted (negative item-to-total correlation)
VOL_06	The quality of the goods produced is not affected by changes in volume	Deleted (negative item-to-total correlation)
VOL_07	The productivity of the manufacturing system is not affected by changes in volume	Deleted (negative item-to-total correlation)
EXP_01	A large number of equipment additions to the manufacturing system can be made	Deleted (negative item-to-total correlation)
LOG_02	The variety of JIT delivery sequences is high	Deleted (negative item-to-total correlation)
LOG_05	Disturbances in delivery times and sequences do not affect the quality of the products	Deleted (negative item-to-total correlation)
PER_06	Employees are equally efficient in all tasks	Deleted (negative item-to-total correlation)
MAF_09	Switching from one operation to the next does not require much effort	Deleted (negative item-to-total correlation)
MAF_10	Machines can perform operations which differ greatly from one another	Deleted (negative item-to-total correlation)

Appendix F: Cover letter and questionnaire (English)

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Audi AG
Purchasing Department
Attn: Mr. Mustermann
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1st November, 2002

Dear Mr. Musterman,

In the last few years the role of sourcing of complex parts (modules) has become increasingly important in the automotive industry. But how can we measure what effects it has on manufacturing flexibility?

This study is a part of my Ph.D. research at the Erasmus University in Rotterdam and is aimed at measuring the effects of modular sourcing on manufacturing flexibility. In order to achieve this, a questionnaire has been developed which you will find attached to this letter. It contains questions that can be answered best by someone who is dealing with module suppliers in day-to-day situations and has a good knowledge about the manufacturing operations.

Your participation is crucial to the success of this study. Therefore I would really appreciate if you could complete this questionnaire (it should not take more than 15 minutes) and return it to me within the next 3 weeks (**not later than 31.11.2002**). To show my gratitude I will be happy to provide you with a summary of the findings of this study that should help you in the assessment of flexibility in your organisation.

Naturally your responses will be held strictly confidential. If you have any further questions please do not hesitate to contact me.

Thank you for your help in advance.
Sincerely,

Peter Miltenburg

Section 1 – Respondent's and supplier's profile

1. What is your functional background?

0	General management	0	Distribution
0	Procurement	0	Quality
0	Production / Logistics	0	Other: ______________________

2. What is your position?

0	Higher management	0	Lower management
0	Middle management	0	Other: ______________________

3. What kind of activities does a module supplier perform?

0	Development	0	Development & production
0	Production	0	Other: ______________________

4. Approximately how many FTEs (Full Time Equivalents) are employed by the module supplier?

0	less than 1.000	0	10.000 - 20.000
0	1.000 – 5.000	0	More than 20.000
0	5.000 – 10.000		

5. What type of modules are developed and produced by the module supplier?

____

____

6. Please indicate the competitive position of the module supplier in comparison to significant competitors concerning the following items.

		much higher	higher	equal	lower	much lower
a)	The amount of new / adjusted products introduced	0	0	0	0	0
b)	The amount of innovations introduced	0	0	0	0	0
c)	The range of product offerings	0	0	0	0	0
d)	The extent of customisation	0	0	0	0	0
e)	Product quality	0	0	0	0	0
f)	Price of product	0	0	0	0	0
g)	Order-to-delivery time	0	0	0	0	0

Section 2 – Modular sourcing and flexibility dimensions

Please indicate to what extent you agree with the following statements concerning MODULAR SOURCING

		Entirely disagree	Dis-agree	Neutral	Agree	Entirely agree
a)	In a modular sourcing relationship the OEM highly depends on the module supplier	0	0	0	0	0
b)	In a modular sourcing relationship the intensity of cooperation is increased	0	0	0	0	0
c)	In a modular sourcing relationship the mutual dependence is high	0	0	0	0	0
d)	In a modular sourcing relationship the supplier needs to have a high level of problem solving ability	0	0	0	0	0

Flexibility dimensions

Process flexibility relates to the number of products that have alternate processing plans and the variety (heterogeneity) of processing operations used without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Expansion flexibility corresponds to the ability of a manufacturing system to accommodate a number and a variety of expansions without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Logistical flexibility corresponds to the ability to control and execute a number of logistical tasks both inbound and outbound with a large variety without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Product flexibility corresponds to the number and heterogeneity of newly introduced products or modifications on existing products that are achieved without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Volume flexibility corresponds to the ability of a manufacturing system to be operated profitably (in the short-term) with a various amount of volume for several products without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Machine flexibility corresponds to the number of operations and the variety of products that can be produced with the use of a machine without incurring negative effects (e.g. time-delays, changes in performance outcomes) when switching from one operation to another.

Personnel flexibility corresponds to the ability to adjust the number of employees and tasks, including the variety of tasks (heterogeneity), without incurring negative effects (e.g. time-delays, changes in performance outcomes) when fluctuations arise.

Please indicate to what extent you agree with the following statements concerning <u>PROCESS FLEXIBILITY</u>.

		Entirely disagree	Dis-agree	Neutral	Agree	Entirely agree
a)	The production flow can be re-routed to parallel assembly lines	0	0	0	0	0
b)	The manufacturing system is fully functional when some machines are not operative	0	0	0	0	0
c)	A large number of product categories are produced in the manufacturing system	0	0	0	0	0
d)	The manufacturing system can quickly changeover to a different product mix	0	0	0	0	0
e)	The choice of processing operations does not affect the quality of the output	0	0	0	0	0
f)	The choice of processing operations does not affect the production costs	0	0	0	0	0

Please indicate to what extent you agree with the following statements concerning <u>EXPANSION FLEXIBILITY</u>.

		Entirely disagree	Dis-agree	Neutral	Agree	Entirely agree
a)	Process improvements can be introduced in the manufacturing system	0	0	0	0	0
b)	The manufacturing system can be expanded easily when needed in the long-term	0	0	0	0	0
c)	Manufacturing system expansions do not affect the quality levels of the output	0	0	0	0	0
d)	Manufacturing system expansions do not affect the throughput time	0	0	0	0	0

Please indicate to what extent you agree with the following statements concerning <u>LOGISTICAL FLEXIBILITY</u>.

		Entirely disagree	Dis-agree	Neutral	Agree	Entirely agree
a)	The production system can handle many different delivery sequences	0	0	0	0	0
b)	The computer-supported quality control of incoming goods reduces flow interruptions	0	0	0	0	0
c)	The cost for changes in inbound and outbound logistic is low	0	0	0	0	0

Please indicate to what extent you agree with the following statements concerning PRODUCT FLEXIBILITY.

		Entirely disagree	Dis-agree	Neutral	Agree	Entirely agree
a)	A large number of new or modified products are introduced each year	0	0	0	0	0
b)	The product configuration can be changed many times during the manufacturing process to accommodate to customer preferences	0	0	0	0	0
c)	Product development lead times are low because of a modular product structure	0	0	0	0	0
d)	The variety of modules / components used allow many different products to be configured	0	0	0	0	0
e)	The time required to change to a different product mix is short	0	0	0	0	0
f)	The performance of the manufacturing system is not affected by a change in product design	0	0	0	0	0
g)	Quality levels of the output are not affected by changing the product mix	0	0	0	0	0

Please indicate to what extent you agree with the following statements concerning VOLUME FLEXIBILITY.

		Entirely disagree	Dis-agree	Neutral	Agree	Entirely agree
a)	The manufacturing system can handle rapidly increasing production volumes	0	0	0	0	0
b)	The output volumes for the different products can be varied largely	0	0	0	0	0
c)	The level of production volume can be changed quickly	0	0	0	0	0
d)	Volume changes can be handled easily	0	0	0	0	0
e)	The manufacturing system can operate profitably at different production volumes	0	0	0	0	0
f)	Process improvements can be introduced to the manufacturing system without creating disturbances	0	0	0	0	0

Please indicate to what extent you agree with the following statements concerning MACHINE FLEXIBILITY.

		Entirely disagree	Dis-agree	Neutral	Agree	Entirely agree
a)	The number of different operations a typical machine can perform is high	0	0	0	0	0
b)	Machines can be re-programmed easily to take over different tasks	0	0	0	0	0
c)	Machine re-tooling times are short	0	0	0	0	0
d)	Machines can perform different types of processing or assembly operations	0	0	0	0	0

e)	Machine changeovers between operations are not expensive	0	0	0	0	0
f)	All machines achieve similar performance across all operations	0	0	0	0	0
g)	The processing time of an operation is not affected by machines choice	0	0	0	0	0
h)	All machines are equally reliable for all operations	0	0	0	0	0

Please indicate to what extent you agree with the following statements concerning <u>PERSONNEL FLEXIBILITY</u>.

		Entirely disagree	Dis-agree	Neutral	Agree	Entirely agree
a)	Many job classifications exist in the workforce	0	0	0	0	0
b)	Employees can perform many different types of tasks	0	0	0	0	0
c)	The number of tasks and employees can easily be varied	0	0	0	0	0
d)	A short time-delay occurs when employees are moved between different tasks	0	0	0	0	0
e)	Employees achieve similar performance levels for all tasks	0	0	0	0	0

THANK YOU FOR YOUR PARTICIPATION!

Appendix G: Cover letter and questionnaire (German)

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Lehrstuhl für Marketing & Organisation
Koordinatoren: Prof. dr. J. Paauwe
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Audi AG
Einkauf Abteilung
Z.h. Herr Mustermann
D-85059 Ingolstadt

1. November, 2002

Sehr geehrter Herr Mustermann,

in den letzten Jahren ist die modulare Zulieferung von komplexen Teilen in der Automobilindustrie immer wichtiger geworden. Aber wie kann man den Einfluss dieser Entwicklung auf die Produktionsflexibilität messen?

Diese Studie ist Teil der praktischen Untersuchungen für meine Doktorarbeit, die ich an der Erasmus Universität in Rotterdam schreibe, und deren Ziel es ist, eine Skala zum Messen der Produktionsflexibilität bezüglich modularem Zuliefern zu entwickeln und anzuwenden. Um dies zu erreichen, habe ich einen Fragebogen entwickelt, den Sie im Anhang finden. Er enthält Fragen, die am Besten von einer Person beantwortet werden können, die sich viel mit den Themen Einkauf bzw. Produktion beschäftigt.

Ihre Teilnahme trägt essentiell zum Erfolg dieser Studie bei. Deswegen wäre ich Ihnen sehr dankbar, wenn Sie den Fragebogen ausfüllen (das sollte ungefähr 15 Minuten dauern) und innerhalb der nächsten 3 Wochen an mich zurück schicken könnten (**spätestens bis 31.11.2002**). Zum Dank werde ich Ihnen, falls Sie interessiert sind, die Zusammenfassung der Ergebnisse meiner Studie senden, die Ihnen dabei helfen sollten, das Maß der Flexibilität in Ihrem Unternehmen einzuschätzen.

Natürlich werden Ihre Antworten streng vertraulich behandelt. Falls Sie Fragen haben, zögern Sie nicht, mich zu kontaktieren. Vielen Dank im Voraus für Ihre Unterstützung.

Mit freundlichen Grüßen,

Peter Miltenburg

Teil 1 – Profil des Befragten und des Zulieferers

1. Was ist Ihre Funktion im Unternehmen?

0	Generelles Management	0	Distribution
0	Einkauf	0	Qualitätssicherung
0	Produktion / Logistik	0	Anderes: ____________________

2. Was ist Ihre Position?

0	Höheres Management	0	Niedrigeres Management
0	Mittleres Management	0	Anderes: ____________________

3. Welche Aktivitäten führt der Modulzulieferer aus?

0	Entwicklung	0	Entwicklung und Produktion
0	Produktion	0	Anderes: ____________________

4. Wie viele FTEs (Full Time Equivalents) sind beim Modulzulieferer beschäftigt?

0	Weniger als 1.000	0	10.000 – 20.000
0	1.000 – 5.000	0	Mehr als 20.000
0	5.000 – 10.000		

5. Welche Module entwickelt / produziert der Modulzulieferer?

____

____

6. Bitte bewerten Sie die Wettbewerbsposition des Modulzuliefers im Vergleich zu Konkurrenten bezüglich folgender Elemente.

		Viel höher	Höher	Gleich	Nied-riger	Viel nie-driger
a)	Anzahl der neu / angepasst eingeführten Produkte	0	0	0	0	0
b)	Anzahl der eingeführten Innovationen	0	0	0	0	0
c)	Bandbreite der Produktpalette	0	0	0	0	0
d)	Möglichkeit der kundenindividuellen Produktion	0	0	0	0	0
e)	Produktqualität	0	0	0	0	0
f)	Produktpreis	0	0	0	0	0
g)	Auftragsdurchlaufzeit	0	0	0	0	0

Teil 2 – Modulares Zuliefern und Dimensionen der Flexibilität

Bitte bewerten Sie, inwiefern Sie folgenden Aussagen bezüglich des MODULAREN ZULIEFERN zustimmen würden

		Vollstdg. ab-lehnen	Ab-lehnen	Neutral	Zustim-men	Vollstdg. zu-stimmen
a)	In einer Modul-Zuliefer-Beziehung ist der OEM stark abhängig vom Modul Zulieferer	0	0	0	0	0
b)	In einer Modul-Zuliefer-Beziehung ist die Kooperation intensiviert	0	0	0	0	0
c)	In einer Modul-Zuliefer-Beziehung ist die gegenseitige Abhängigkeit hoch	0	0	0	0	0
d)	In einer Modul-Zuliefer-Beziehung muss der Zulieferer in einem hohen Maße dazu fähig sein, Probleme zu lösen	0	0	0	0	0

Flexibiltätsdimensionen

Prozessflexibilität bezieht sich auf die Anzahl der Produkte, die auf unterschiedliche Weise bearbeitet, und die Vielfalt der Prozessschritte, die eingesetzt werden können, ohne dass sich dadurch negative Auswirkungen bei Schwankungen des Systems ergeben (z.B. Zeitverzögerungen, Veränderungen der Leistung).

Expansionsflexibilität bezieht sich auf die Möglichkeit des Produktionssystems, Anzahl und Bandbreite der Expansionen zu variieren, ohne dass sich dadurch negative Auswirkungen bei Schwankungen des Systems ergeben (z.B. Zeitverzögerungen, Veränderungen der Leistung).

Logistikflexibilität bezieht sich auf die Möglichkeit des Produktionssystems, mehrere und unterschiedliche logistische Aufgaben (sowohl externe als auch interne) durchzuführen, ohne dass sich dadurch negative Auswirkungen bei Schwankungen des Systems ergeben (z.B. Zeitverzögerungen, Veränderungen der Leistung).

Produktflexibilität bezieht sich auf Anzahl und Vielfalt der Produkte, die neu eingeführt bzw. angepasst werden können, ohne dass sich dadurch negative Auswirkungen bei Schwankungen des Systems ergeben (z.B. Zeitverzögerungen, Veränderungen der Leistung).

Volumenflexibilität bezieht sich auf die Möglichkeit eines Produktionssystems, auf kurze Sicht auch bei Volumenschwankungen in der Herstellung unterschiedlicher Produkte profitabel zu arbeiten, so dass sich keine negativen Auswirkungen ergeben (z.B. Zeitverzögerungen, Veränderungen der Leistung).

Maschinenflexibilität bezieht sich auf Anzahl und Vielfalt der Produkte, die von der gleichen Maschine hergestellt werden können, ohne dass sich dadurch negative Auswirkungen bei Schwankungen des Systems ergeben (z.B. Zeitverzögerungen, Veränderungen der Leistung).

Personalflexibilität bezieht sich auf die Möglichkeit, die Anzahl des Personals und die Heterogenität der Aufgaben je nach Bedarf anzupassen, ohne dass sich dadurch negative Auswirkungen bei Schwankungen des Systems ergeben (z.B. Zeitverzögerungen, Veränderungen der Leistung).

Bitte bewerten Sie, inwiefern Sie folgenden Aussagen bezüglich der PROZESSFLEXIBILITÄT zustimmen würden.

		Vollstdg. ab-lehnen	Ab-lehnen	Neutral	Zustim-men	Vollstdg. zu-stimmen
a)	Der Produktionsfluss kann auf parallele Fertigungslinien umgeleitet werden	0	0	0	0	0
b)	Das Produktionssystem kann mehrere Prozesse für unterschiedliche Produkte durchführen	0	0	0	0	0
c)	Im Produktionssystem stehen unterschiedliche Prozesse für die Fertigung unterschiedlicher Produkte zur Verfügung	0	0	0	0	0
d)	Das Produktionssystem kann schnell auf einen anderen Produkt-Mix umgestellt werden	0	0	0	0	0
e)	Die Prozesswahl hat keine Auswirkungen auf die Qualität der Produkte	0	0	0	0	0
f)	Die Prozesswahl hat keine Auswirkungen auf die Produktionskosten	0	0	0	0	0

Bitte bewerten Sie, inwiefern Sie folgenden Aussagen bezüglich EXPANSIONSFLEXIBILITÄT zustimmen würden.

		Vollstdg. ab-lehnen	Ab-lehnen	Neutral	Zustim-men	Vollstdg. zu-stimmen
a)	Prozessverbesserungen können im Produktionssystem eingeführt werden	0	0	0	0	0
b)	Das Produktionssystem kann auf lange Sicht einfach erweitert werden.	0	0	0	0	0
c)	Expansionen des Produktionssystems haben keine Auswirkungen auf die Qualität der Produkte	0	0	0	0	0
d)	Expansionen des Produktionssystems haben keine Auswirkungen auf die Durchlaufzeit.	0	0	0	0	0

Bitte bewerten Sie, inwiefern Sie folgenden Aussagen bezüglich der <u>LOGISTIKFLEXIBILITÄT</u> zustimmen würden.

		Vollstdg. ablehnen	Ablehnen	Neutral	Zustimmen	Vollstdg. zustimmen
a)	Hohe Schwankungen in Zulieferzeiten können leicht abgefangen werden	0	0	0	0	0
b)	Computerunterstützte Eingangskontrolle reduziert Prozessunterbrechnungen	0	0	0	0	0
c)	Kosten für die Änderung interner und externer logistischer Abläufe sind niedrig	0	0	0	0	0

Bitte bewerten Sie, inwiefern Sie folgenden Aussagen bezüglich der <u>PRODUKTFLEXIBILITÄT</u> zustimmen würden.

		Vollstdg. ablehnen	Ablehnen	Neutral	Zustimmen	Vollstdg. zustimmen
a)	Viele neue / angepasste Produkte werden jedes Jahr eingeführt	0	0	0	0	0
b)	Die Produktkonfiguration kann dem Kundenwunsch entsprechend oft angepasst werden	0	0	0	0	0
c)	Eine modulare Produktstruktur verkürzt die Produktentwicklungszeiten	0	0	0	0	0
d)	Die Vielfalt der Module / Komponenten erlauben viele unterschiedliche Konfigurationen	0	0	0	0	0
e)	Die Zeit, die benötigt wird, um auf einen anderen Produkt-Mix umzustellen, ist kurz	0	0	0	0	0
f)	Die Änderung des Produkt-Designs hat keine Auswirkungen auf die Leistung des Produktionssystems	0	0	0	0	0
g)	Die Änderung des Produkt-Mixes hat keine Auswirkungen auf die Produktqualität	0	0	0	0	0

Bitte bewerten Sie, inwiefern Sie folgenden Aussagen bezüglich der <u>VOLUMENFLEXIBILITÄT</u> zustimmen würden.

		Vollstdg. ablehnen	Ablehnen	Neutral	Zustimmen	Vollstdg. zustimmen
a)	Das Produktionssystem kann Volumenänderungen schnell bewältigen	0	0	0	0	0
b)	Das Produktionsvolumen für unterschiedliche Produkte kann stark variieren	0	0	0	0	0
c)	Das Produktionsvolumen kann schnell geändert werden	0	0	0	0	0
d)	Volumenveränderungen können einfach gehandhabt werden	0	0	0	0	0

e)	Das Produktionssystem kann bei verschiedenen Produktionsvolumina profitabel arbeiten	0	0	0	0	0
f)	Prozessverbesserungen können im Produktionssystem eingeführt werden, ohne dass es dabei zu Störungen kommt	0	0	0	0	0

Bitte bewerten Sie, inwiefern Sie folgenden Aussagen bezüglich der <u>MASCHINENFLEXIBILITÄT</u> zustimmen würden.

		Vollstdg. ab-lehnen	Ab-lehnen	Neutral	Zustim-men	Vollstdg. zu-stimmen
a)	Die Anzahl der Aktivitäten, die eine Maschine durchführen kann, ist hoch	0	0	0	0	0
b)	Maschinen können einfach auf die Übernahme verschiedener Aufgaben umprogrammiert werden	0	0	0	0	0
c)	Die Maschinenumrüstungszeiten sind kurz	0	0	0	0	0
d)	Maschinen können unterschiedlichen Aktivitäten angepasst werden	0	0	0	0	0
e)	Die Kosten des Maschinenwechsels zwischen verschiedenen Aktivitäten sind niedrig	0	0	0	0	0
f)	Die Leistung aller Maschinen ist vergleichbar	0	0	0	0	0
g)	Die Wahl der Maschine hat keine Auswirkungen auf die Produktionszeit	0	0	0	0	0
h)	Die Zuverlässigkeit aller Maschinen für alle Aktivitäten ist vergleichbar	0	0	0	0	0

Bitte bewerten Sie, inwiefern Sie folgenden Aussagen bezüglich der <u>PERSONALFLEXIBILITÄT</u> zustimmen würden.

		Vollstdg. ab-lehnen	Ab-lehnen	Neutral	Zustim-men	Vollstdg. zu-stimmen
a)	Für die Arbeit des Personals existieren viele Klassifikationen	0	0	0	0	0
b)	Das Personal kann viele unterschiedliche Aufgaben ausführen	0	0	0	0	0
c)	Die Anzahl der Aufgaben und des Personals können leicht geändert werden	0	0	0	0	0
d)	Eine minimale Zeitverzögerung entsteht, wenn Personal für eine Aufgabe ausgetauscht wird	0	0	0	0	0
e)	Das Personal erbringt ähnliche Leistungen bei allen Aufgaben	0	0	0	0	0

VIELEN DANK FÜR IHRE TEILNAHME!

Appendix H: Detailed results of measurement purification

FACTOR MODEL								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
MAF_01	0,88							
MAF_02	0,84							
MAF_03	0,80							
MAF_06	0,77							
MAF_07	0,74							
PRO_04		0,86						
PRO_02		0,82						
PRO_05		0,78						
PRO_06		0,73						
VOL_05			0,83					
VOL_04			0,82					
VOL_02			0,80					
PRC_01				0,85				
PRC_07				0,79				
PRC_05				0,68				
PRC_06				0,46				
EXP_02					0,79			
EXP_03					0,78			
EXP_04					0,61			
PER_02						0,89		
PER_04						0,87		
MOD_02							0,87	
MOD_03							0,80	
LOG_04								0,86
LOG_01								0,67

Extraction method: principal component
Rotation method: Varimax with Kaiser Normalisation

The results of the purified factor model are specified in the table above. Furthermore, a description of the scale items is given in the table below which includes: sum score, mean score, standard deviation, variance, skewness[54], and kurtosis[55].

	Sum	Mean	Standard deviation	Variance	Skewness	Kurtosis		Sum	Mean	Standard deviation	Variance	Skewness	Kurtosis
PRC_01	211	4,06	0,70	0,49	-0,08	-0,88	**LOG_01**	233	4,48	0,58	0,33	-0,56	-0,64
PRC_05	218	4,19	0,72	0,51	-0,30	-0,97	**LOG_03**	216	4,15	0,75	0,56	-0,26	-1,16
PRC_06	223	4,29	0,70	0,48	-0,46	-0,82	**LOG_04**	230	4,42	0,61	0,37	-0,52	-0,58
PRC_07	218	4,19	0,69	0,47	-0,27	-0,82	**PER_01**	218	4,19	0,60	0,35	-0,08	-0,28
VOL_01	217	4,17	0,81	0,66	-0,33	-1,39	**PER_02**	212	4,08	0,71	0,50	-0,11	-0,95
VOL_02	214	4,12	0,70	0,50	-0,17	-0,92	**PER_03**	206	3,96	0,52	0,27	-0,06	0,90
VOL_03	204	3,92	0,58	0,34	0,08	0,06	**PER_04**	218	4,19	0,63	0,39	-0,16	-0,48
VOL_04	216	4,15	0,75	0,56	-0,55	-0,07	**PER_05**	210	4,04	0,62	0,38	0,04	-0,31
VOL_05	208	4,00	0,77	0,59	0,00	-1,27	**MAF_01**	218	4,19	0,66	0,43	-0,22	-0,66
VOL_08	214	4,12	0,68	0,46	-0,14	-0,74	**MAF_02**	230	4,42	0,67	0,44	-0,74	-0,50
EXP_02	222	4,27	0,63	0,40	-0,27	-0,59	**MAF_03**	220	4,23	0,67	0,46	-0,71	1,10
EXP_03	225	4,33	0,58	0,34	-0,20	-0,59	**MAF_04**	197	3,79	0,61	0,37	0,12	-0,38
EXP_04	218	4,19	0,60	0,35	-0,08	-0,28	**MAF_05**	225	4,33	0,58	0,34	-0,20	-0,59
EXP_05	220	4,23	0,76	0,57	-0,42	-1,12	**MAF_06**	222	4,27	0,63	0,40	-0,27	-0,59
PRO_01	199	3,83	0,73	0,54	0,29	-1,06	**MAF_07**	215	4,13	0,60	0,35	-0,04	-0,15
PRO_02	212	4,08	0,76	0,58	-0,13	-1,24	**MAF_08**	216	4,15	0,70	0,49	-0,22	-0,88
PRO_03	205	3,94	0,67	0,45	0,07	-0,68	**MOD_01**	226	4,35	0,59	0,35	-0,26	-0,62
PRO_04	206	3,96	0,77	0,59	0,07	-1,27	**MOD_02**	220	4,23	0,65	0,42	-0,25	-0,62
PRO_05	211	4,06	0,75	0,57	-0,10	-1,19	**MOD_03**	216	4,15	0,70	0,49	-0,22	-0,88
PRO_06	214	4,12	0,70	0,50	-0,17	-0,92	**MOD_04**	212	4,08	0,76	0,58	-0,13	-1,24
PRO_07	211	4,06	0,70	0,49	-0,08	-0,88							

[54] Skewness is a measure of the asymmetry of a distribution. The normal distribution is symmetric, and has a skewness value of zero.

[55] Kurtosis is a measure of the extent to which observations cluster around a central point. For a normal distribution, the value of the kurtosis statistic is 0.

Appendix I: Purified scale items

Items for process flexibility

ITEM	DESCRIPTION	SOURCE(S)
PRC_01	The production flow can be re-routed to parallel assembly lines	Rieken (1995)
PRC_05	A large number of product categories are produced in the manufacturing system	Suarez *et al.* (1995)
PRC_06	The manufacturing system can quickly changeover to a different product mix	Dixon (1992)
PRC_07	The choice of processing operations does not affect the quality of the output	Proposed

Items for volume flexibility

ITEM	DESCRIPTION	SOURCE(S)
VOL_02	The output volumes for the different products can be varied largely	Koste (1999)
VOL_04	Volume changes can be handled easily	Proposed
VOL_05	The manufacturing system can operate profitably at different production volumes	Sethi & Sethi (1990); Gupta & Somers (1996)

Items for expansion flexibility

ITEM	DESCRIPTION	SOURCE(S)
EXP_02	Process improvements can be introduced in the manufacturing system	Sethi & Sethi (1990); Gupta & Somers (1996)
EXP_03	The manufacturing system can be expanded easily when needed in the long-term	Gupta & Sommer (1996); Sethi & Sethi (1990)
EXP_04	Manufacturing system expansions do not affect the quality levels of the output	Koste (1999)

Items for logistical flexibility

ITEM	DESCRIPTION	SOURCE(S)
LOG_01	The production system can handle many different delivery sequences	Proposed
LOG_04	The cost for changes in inbound and outbound logistic is low	Proposed

Items for product flexibility

ITEM	DESCRIPTION	SOURCE(S)
PRO_02	The product configuration can be changed many times during the manufacturing process to accommodate to customer preferences	Proposed
PRO_03	Product development lead times are low because of a modular product structure	Gupta & Somers (1996)
PRO_04	The variety of modules / components used allow many different products to be configured	Proposed
PRO_05	The time required to change to a different product mix is short	Upton (1995)
PRO_06	The performance of the manufacturing system is not affected by a change in product design	Proposed

Items for machine flexibility

ITEM	DESCRIPTION	SOURCE(S)
MAF_01	The number of different operations a typical machine can perform is high	Carter (1986); Gupta & Somers (1996)
MAF_02	Machines can be re-programmed easily to take over different tasks	Proposed
MAF_03	Machine re-tooling times are short	Zäpfel (1982)
MAF_06	All machines achieve similar performance across all operations	Koste (1999)
MAF_07	The processing time of an operation is not affected by machines choice	Benjaafar (1994)

Items for personnel flexibility

ITEM	DESCRIPTION	SOURCE(S)
PER_02	Employees can perform many different types of tasks	Chen *et al.* (1992)

PER_04	A short time-delay occurs when employees are moved between different tasks	Malhotra *et al.* (1993)

Items for modular sourcing

ITEM	DESCRIPTION	SOURCE(S)
MOD_02	In a modular sourcing relationship the intensity of cooperation is increased	Eicke & Femerling (1991); Wolters (1995)
MOD_03	In a modular sourcing relationship the mutual dependence is high	Eicke & Femerling (1991)

Samenvatting in het Nederlands

De interesse in het modulair toeleveren in de automobiel industrie is de afgelopen jaren sterk gestegen. Dit kan worden verklaard aan de hand van factoren als toenemende complexiteit, hoge ontwikkelingskosten, kortere product levenscycli en een relatief lage rentabiliteit van automobiel fabrikanten (Original Equipment Manufacturers = OEMs).

Het modulair toeleveren heeft betrekking op het uitbesteden van de ontwikkeling en productie van complexe componenten voor personenauto's of vrachtwagens. Deze zogenaamde 'modules' worden direct aan de productiehal van de autofabrikant geleverd en kunnen vervolgens meteen in de carrosserie worden ingebouwd. Bij de sturing en het controleren van deze processen van vele toeleveranciers in een netwerk, spelen de 'just-in-time' (JIT) en 'just-in-sequence' (JIS) principes een belangrijke rol.

In dit onderzoek worden de effecten van het modulair toeleveren op de productie flexibiliteit in de Duitse automobiel industrie onderzocht. Dit wordt gedaan omdat fabrikanten als DaimlerChrysler, BMW, Porsche, en Volkswagen als experts kunnen worden beschouwd met betrekking tot het modulair toeleveren.

Ten eerste wordt er in deze studie gekeken naar de directe effecten van modulair toeleveren op verschillende dimensies van flexibiliteit. Ten tweede wordt onderzocht welke factoren van invloed zijn op de relatie tussen deze twee onderzoeksobjecten (zowel positief als negatief). Bij de onderzochte factoren wordt onderscheid gemaakt tussen factoren die de sterkte van de relatie tussen modulair toeleveren en de flexibiliteit beïnvloeden (moderatoren) en factoren die onafhankelijk van modulair toeleveren de mate van flexibiliteit beïnvloeden (quasi-moderatoren). Ten derde wordt onderzocht naar welke operationele dimensies van productie flexibiliteit een onderscheid kan worden gemaakt en hoe deze dimensies gemeten kunnen worden.

In deze studie wordt een combinatie van onderzoeksmethoden gebruikt om het conceptueel model te ontwikkelen en te valideren. In het eerste deel van deze studie is gebruik gemaakt van exploratieve case studies om niet alleen modulair toeleveren in relatie tot productie flexibiliteit te onderzoeken, maar ook de factoren van invloed. In het tweede deel van het onderzoek wordt van een enquête gebruik gemaakt om de relatie tussen modulair toeleveren en productie flexibiliteit nader te bestuderen. Deze onderzoeksopzet maakt het mogelijk goed gefundeerde conclusies te trekken. Met andere woorden, als de twee verschillende onderzoeksmethoden tot dezelfde conclusies leiden, dan zijn deze resultaten eenduidiger dan op basis van één onderzoeksmethode.

Wat zijn de effecten van modulair toeleveren op de productie flexibiliteit?

Om de effecten van het modulair toeleveren te kunnen analyseren, wordt een onderscheid gemaakt tussen een co-leverancier, hoofdleverancier, en een module leverancier. Een co-leverancier heeft een hoge mate van proces competentie terwijl een hoofdleverancier zijn kernvaardigheden op het terrein van producten heeft. Een module toeleverancier heeft, in tegenstelling, zowel en hoge product als mede een proces competentie en ontwikkelt vaak bepaalde technologieën voor eigen risico.

Voor deze verschillende typen toeleveranciers wordt, op basis van een ontwikkelde schaal, een beoordeling gemaakt van de mate van flexibiliteit. Deze beoordeling wordt gedaan voor zeven operationele dimensies van productie flexibiliteit. Op basis van de analyse kan de volgende hoofdconclusie worden getrokken: modulair toeleveren heeft een positieve invloed op alle zeven dimensies (proces, volume, expansies, logistiek, product, machine, en personeel) van productie flexibiliteit. Deze relaties worden zowel door zowel de exploratieve case studies als ook door de enquête bevestigd.

Ten eerste beïnvloedt modulair toeleveren op een positieve manier de mate van proces flexibiliteit. Module toeleveranciers maken hoofdzakelijk gebruik van batch productie die als flexibeler dan massa productie processen worden beschouwd. Massa productie processen worden veel gebruikt door co- en hoofdleveranciers en stellen deze in staat schaalvoordelen te creëren. Ten tweede beïnvloedt modulair toeleveren op een positieve manier de mate van volume flexibiliteit. Een hoge mate van volume flexibiliteit betekent dat een toeleverancier in staat is snel op oscillaties in de vraag te reageren. Ten derde wordt de mate van expansie flexibiliteit positief beïnvloed door modulair toeleveren. De expansie flexibiliteit betreft de mate van volume flexibiliteit op langere termijn en is niet gebonden aan de huidige productie capaciteit.

Ten vierde beïnvloedt modulair toeleveren op een positieve manier de mate van logistieke flexibiliteit. JIT en JIS vaardigheden zijn bij de module toeleverancier beter ontwikkeld in vergelijking met de andere typen toeleveranciers. Verder wordt een module toeleverancier als flexibeler beschouwd met betrekking tot de mate van product flexibiliteit. Dit kan verklaard worden door het feit dat module toeleveranciers naast een hoge mate van proces kennis ook complete modules ontwikkelen en dus veel product kennis en competities hebben. Verder investeren module toeleveranciers veel in technologieën omtrent machines en worden beschouwd als flexibeler dan co- en hoofdtoeleveranciers. Daar module toeleveranciers gebruik maken van moderne machines, zijn ze in staat specifieke taken uit te voeren die eenvoudig voor andere producten aangepast kunnen worden. Ten slotte zijn module toeleveranciers flexibeler met betrekking tot de functionele flexibiliteit van het personeel.

Welke factoren (moderator en quasi moderatoren) zijn van invloed op de relatie tussen modulair toeleveren en productie flexibiliteit (zowel positief als negatief)?

Ten eerste wordt de relatie tussen modulair toeleveren en productie flexibiliteit positief beïnvloedt door een reductie van complexiteit. Het aantal verschillende product modellen dat wordt aangeboden door OEM's is de afgelopen decennia continu gestegen. De hiermee verbonden gestegen complexiteit vormt een groot probleem voor de besturing van het productie systeem. Het reduceren van de complexiteit op proces- en productniveau is één van de belangrijkste redenen meer modules door een toeleverancier te laten ontwikkelen en te produceren. Ten tweede heeft het reduceren van de mate van verticale integratie (van de waarde toevoegende activiteiten) een positieve invloed op de relatie tussen de twee onderzoeksobjecten. Op basis van de analyse van de mate van verticale integratie kan worden geconcludeerd dat die de afgelopen jaren sterk afgenomen is. Ten derde heeft een hoog kennis niveau van toeleveranciers met betrekking tot processen en producten een positieve invloed op de relatie tussen modulair toeleveren en productie flexibiliteit. Omdat module toeleveranciers steeds meer in staat zijn competenties op het gebied van vormgeving en technologie te ontwikkelen, worden zij sterker gevraagd voor het ontwikkelen van oplossingen. Ten vierde beïnvloeden minder hiërarchische coördinatie structuren de relatie tussen de twee onderzoeksobjecten positief. Daar er onzekerheid bestaat over de toekomstige technologische ontwikkelingen worden er over het algemeen korte termijn (markt) contracten afgesloten. Ten slotte heeft het reduceren van procesverantwoordelijkheid een negatieve invloed op de relatie tussen modulair toeleveren en productie flexibiliteit. Indien de verantwoordelijkheid voor de productie overgedragen wordt aan toeleveranciers leidt dit tot een lagere flexibiliteit en prestatie van het productie systeem. Hieruit blijkt dat het produceren van technologisch complexe producten een bron is voor het verkrijgen van een concurrentie voordeel is en niet mag worden uitbesteed aan derde partijen.

Als quasi-moderator variabelen zijn technologische ontwikkelingen en leer effecten geïdentificeerd worden. Quasi-moderator variabelen zijn variabelen die niet direct gerelateerd zijn aan modulair toeleveren maar wel een invloed hebben op de mate van flexibiliteit. Zo leiden investeringen in technologie tot een verbetering van de flexibiliteit zonder dit direct aan modulair toeleveren gerelateerd is. Ten tweede zijn leerervaringen een belangrijke basis voor het verbeteren van de flexibiliteit en het reduceren van productiekosten. Leerervaringen zijn, in tegenstelling tot schaalvoordelen, gerelateerd aan gemiddelde productiekosten en afhankelijk van het totaal geproduceerde volume.

De gemiddelde kosten per geproduceerde eenheid dalen bij een verhoging van het totale aantal geproduceerde eenheden.

Naar welke operationele dimensies van productie flexibiliteit kan een onderscheid worden gemaakt en hoe kunnen deze dimensies gemeten worden?

In dit onderzoek wordt een onderscheid gemaakt naar de volgende operationele dimensies van productie flexibiliteit: proces, volume, expansie, logistiek, product, machine en personeel. Deze dimensies tezamen vormen het complete ‘domein’ van productie flexibiliteit en kunnen op twee niveaus worden gezien. Het eerste niveau wordt gevormd door functionele dimensies van productie flexibiliteit: proces, volume, expansie, logistiek, en product flexibiliteit. Het tweede (productiemiddelen) niveau wordt gevormd door personeel en machine flexibiliteit. Deze twee laatst genoemde dimensies zijn sterk van elkaar afhankelijk en fungeren samen als basis voor de andere (functionele) dimensies. Voor elk van deze dimensies zijn meetschalen ontwikkeld op basis van de bestaande literatuur, case studies en interviews met experts. Deze schalen zijn gezuiverd en getest met behulp van de Churchill (1979) methode en zijn beschreven in bijlage I.

Door, zowel op basis van exploratieve case studies als een enquête, conclusies te trekken met betrekking tot de effecten van modulair toeleveren op de flexibiliteit in de productie, is dit onderzoek hopelijk in staat een bijdrage te leveren aan een beter begrip van de onderzoeksobjecten en de relatie tussen beiden. Wellicht dat dit onderzoek de theoretische verwachte voordelen van modulair toeleveren dichter bij de praktijk kan brengen.

Curriculum Vitæ

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02/97 - 06/98:	Stichting Ceres, Haarlem (NL); Start-up of own company; A direct marketing agency for general interest magazines.

List of abbreviations

ABC:	Activity Based Costing
ADL:	Arthur D. Little
ATC:	Average Total Costs
AVE:	Average Variance Extracted
BTO:	Build To Order
CAD:	Computer Aided Design
CAM:	Computer Aided Manufacturing
CFA:	Confirmatory Factor Analysis
CNC:	Computer Numeric Control
CODP:	Customer Order Decoupling Point
D:	Demand
d.f.	degree of freedom
DFÜ:	Datenfernübertragung
EDI:	Electronic Data Interchange
EFA:	Exploratory Factor Analysis
FMS:	Flexible Manufacturing Systems
FTE:	Full Time Equivalent
GFI:	Goodness of Fit Indices
IT:	Information Technology
ICDP:	International Car Distribution Program
JIT:	Just In Time
JIS:	Just In Sequence
MC:	Marginal Costs
MPV:	Multi Purpose Vehicle
MR:	Marginal Revenues
n.a.:	not applicable
OEM:	Original Equipment Manufacturer
PCP:	Product Concept Planning
R&D:	Research & Development
RMSEA:	Root Mean Square Error of Approximation
RNI:	Relative Non-centrality Indices
ROCE:	Return On Capital Employed
SCP:	Structure Conduct Performance
SCM:	Supply Chain Management
SIC:	Standard Industry Code
SKD:	Semi Knocked Down
SUV:	Sports Utility Vehicle
TPPM:	Technology Product Process Market
TLI:	Tucker Lewis Indices
UK:	United Kingdom
VDA:	Verband der Deutschen Automobilindustrie
VDI:	Verein Deutscher Ingenieure
WW II:	World War II

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Effects of Modular Sourcing on Manufacturing Flexibility in the Automotive Industry

Modular sourcing represents a departure from 'traditional' sourcing methods since it reduces the process and product related complexity. The importance of this concept to the automotive industry has been increasing tremendously the last few years and entails a re-structuring of automotive supply chains. In a modular sourcing relationship a supplier develops and produces a complex part of a vehicle (e.g. front-end including lights) on behalf of the vehicle manufacturer. This study focuses on the effects of modular sourcing on the flexibility of manufacturing systems in the automotive industry. Based on a solid theoretical analysis, a conceptual framework is developed in this study, which observes several actors and influential variables. In order to develop and validate this conceptual framework both exploratory case studies (at DaimlerChrysler, Porsche, Volkswagen, BMW) and quantitative analysis have been used. The results of this study demonstrate that the flexibility of the manufacturing system is positively affected by the application of modular sourcing. However, outsourcing too many activities can result in quality problems, higher costs, and can actually reduce the level of manufacturing flexibility.

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