MATTHIJS J.J. WOLTERS

# The Business of Modularity

# and the Modularity of Business

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Modulariteitszaken en Zakelijke Modulariteit

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Aan mijn grootouders

# VOORWOORD

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Matthijs J.J. Wolters
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# RESEARCH MODULE 1:

# INTRODUCTION

## CHAPTER 1 INTRODUCTION

This dissertation deals with the concept of modularity, a concept that is used in many different fields of research and applications. With the rise of Electronic Commerce, globalization of markets and the shifting nature of customer demand for increased product variety and higher quality, organizations have to compete on flexibility and responsiveness instead of on standardized products and services alone (Davis 1987, Pine 1993, Feitzinger & Lee 1997). Business modularity may well be the answer to many of the challenges associated with such a transfer.

The main research objective of this dissertation is to investigate how and to what extent business networks can use modularity to become more responsive and flexible, without increasing their costs. An often-used term for this is mass-customization: offering customized products at the price of mass-produced alternatives.

The justification for carrying out this research on business modularity stems from a number of developments and findings in management literature and practice. The first is the before mentioned desire of and need for organizations to customize their products according to the requirements of their customers. Increasingly, these customers demand individual and personalized products and additional services, instead of the standard, mass-produced ones. Organizations struggle with the question how they should accomplish this. The following example nicely illustrates how Dell Computing handles on-demand selling of relatively cheap customized computers to their customers.

Dell Computer of Round Rock, Texas, has proven that complex manufactured products can be made to order (Dell 1999). Using the telephone or the Internet, customers describe the computer they want, the shape of the cabinet and size of the monitor screen, the speed of the microprocessor, the capacity of the hard drive. Other choices involve keyboards, mouses, video cards, modems, speakers, data-storage systems and software. The number of possible combinations is staggering - almost 16 million for desktop models alone. Dell begins assembling a computer only after it receives an order and then ships the finished product directly to the customer's home or business within a few days. Michael Dell started his $16 billion computer business in a University of Texas dorm room in 1983 on the basis of low fixed cost. Dell's masterstroke: build to order and do it quickly. Customization would lose its value if customers had to wait months for their computers. The Internet allows Dell to find out what each customer wants, instantly and cheaply. Continuous-flow manufacturing cuts the cost of customizing: 35 cargo doors line both ends of Dell's new Round Rock manufacturing facility. On one side, suppliers deliver components throughout the day. On the other, workers load finished products onto trucks. Actual assembly takes five minutes. Even adding time for loading software and testing for quality, the whole process takes just four hours. By economizing on spare parts, product inventory, delivery and every other step of the process, the company provides a customized product at a competitive price.

Another important development is the emerging use of Information and Communication Technology (ICT), which is viewed as *the* technological enabler of the previously mentioned developments (Cash & Konsynski 1985, Ives & Mason 1990, Malone & Rockart 1993, Lucas & Baroudi 1994, Venkatraman 1994). ICT could also support and enable the use of more modular designs. It can be an enabler of new processes of collaboration. Those new processes must incorporate a high degree of flexibility in order to constantly being able to quickly adjust to the changing environment.

In line with previous development, more and more organizations view the benefits of supply chain management and try to find the right balance and coherence between their internal processes and those of their suppliers and other external parties, like their customers. They become aware that all of their departments are intertwined, not only with each other, but also with those of their suppliers, distributors, wholesalers and even customers. Organizations are trying to redesign their internal processes as well as their relations with their suppliers and business partners to benefit as much as possible from the new technologies and business opportunities and to obtain as much value as possible from their customers (Jarvenpaa & Ives 1994, Anderson & Narus 1995, Ashkenas et al. 1996, Vervest & Dunn 2000). New strategic alternatives and organizational forms emerge, such as virtual organizations, where the suitability of the current business models, originating from the traditional industrial economy is questioned (Venkatraman & Henderson 1998).

One of the most successful examples of a company that makes use of both the new technologies available in combination with a new perspective on supply chain management is Cisco systems. Their Networked Supply Chain Management Solution helps Cisco to build an extended enterprise to accommodate higher order volume while minimizing administrative overhead. It fuses supply chain constituents - partners, suppliers, manufacturers, distributors, retailers, and customers - into a networked extension of a single enterprise to serve the customer. Each constituent within the supply chain gains value and has secure access to key business information and the power to make its own decisions, magnifying the speed, responsiveness, and efficiency of the traditional company. The benefits of a networked supply chain include:

- Faster inventory turns throughout the supply chain, reducing both inventory carrying costs and a product's overall cost base
- Enhanced customer satisfaction through online order entry and configuration; customers also receive products faster through rapid sharing of customer demand information across the supply chain
- Shorter engineering-to-production cycle times to increase market share
- Flexibility to design, ramp, and retire products rapidly in response to market demand
- Ability to sustain product quality while outsourcing major portions of the fulfillment process

More than 75 percent of Cisco product orders were placed via the Internet in 1999 - over $22 million in business each day. Cisco outsources 55 percent of its product fulfillment to its supply partners - these products are built and shipped directly to customers, never touching Cisco hands from order through fulfillment.

An important place in these examples is set aside for business modularity. It is closely related to all of the before mentioned aspects. It is supposed to enable affordable customization and designing modular supply chains may be viewed as a special and useful type of supply chain management. Subsequently, the use of ICT could further increase the benefits of using a modular (virtual) approach. However, exactly how this should be done and when it is especially useful, is unclear for many companies - that want to become as successful as Dell or Cisco. In this dissertation, we will try to show what the use of modularity in an (inter-) organizational environment can offer to these organizations.

An attempt has been made to design this dissertation in a modular manner as well, i.e. in independent, but related modules. The dissertation consists of four different ‘dissertation modules’, where each module subsequently consists of a number of chapters. The modules can be read independently, although to obtain ‘the full picture’ it is recommended to read them all, while they also have been written accordingly.

The first module (this one) is a small introductory module, describing the justification for carrying out this research and the structure of this dissertation.

The second module (chapters 2, 3 and 4) deals with the development and empirical validation of the process modeling approach Modular Network Design (MND) as described by Hoogeweegen (1997). The approach was designed to support organizations in redesigning their business processes to make them more flexible and responsive towards customer demand. The concept of modularity played an important role in the development of the approach. MND has been implemented in a Decision Support System (DSS) and subsequently applied at the air cargo sector to validate the underlying propositions of the approach. The central research question of this module is:

**Question One:**
**How and to what extent does MND support the design of customized cost-efficient business networks?**

The third research module (chapters 5, 6 and 7), entitled Business Modularity in Three Dimensions, further investigates the theoretical aspects of modularity as well as its practical usage. The central research question of this research module is:

**Question Two:**
**How can modularity enhance the performance of business networks?**

Based on an extensive literature review and the findings of the second research module, a theoretical framework has been developed, which tries to explain how and under what circumstances business networks should employ modularity to improve their performance and which contingent factors influence the relationship between modularity and performance. The central proposition of this framework is that a concurrent, modular design increases the performance of interorganizational business networks in general and a mass-customization strategy in particular. In other words, we will try to show that organizations that analogously design their business network in a modular fashion in all three dimensions (product, process and supply chain) will perform better than organizations that do not. The framework has been further developed and initially tested in the Dutch housing industry. The outcomes of this analysis have been described in chapter 6. Chapter 7 describes further validation of the research framework by means of an extensive business survey among approximately 200 (mass-) customizing organizations.

The last module (chapter 8) contains the overall conclusions together with a number of theoretical and practical implications of these conclusions. It is completed by presenting several suggestions for further research on business modularity and related topics. In the end, this dissertation will hopefully shed more light on the concept of modularity, its possibilities to use it in a business environment and how organizations that want to apply a more modular approach may be supported in doing so. The following scheme in figure 1.1 depicts the dissertation structure in a graphical format:

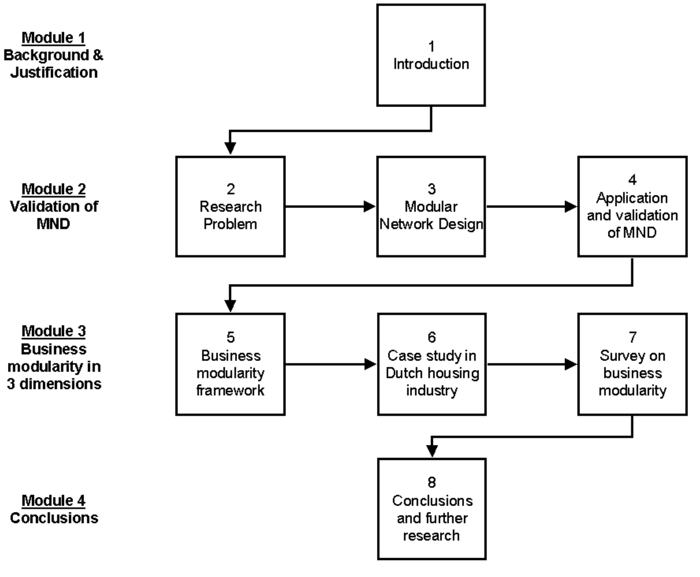


**Figure 1.1: Dissertation structure**

# RESEARCH MODULE 2:

# VALIDATION OF MODULAR NETWORK DESIGN

## CHAPTER 2 BACKGROUND AND RESEARCH SET UP

### *2.1 Introduction*

Many organizations struggle with the question how the transition from traditional, rigid structures to more responsive and customer-oriented business models should take place. Questions arise such as where to begin, which processes to address, which technologies to use and exactly which business models to apply in specific business environments. Organizations are looking for procedures, methods and theories that could support the transition process and help them answer previous questions.

One of such methods, Modular Network Design (Hoogeweegen 1997) is the focal point of attention of this second dissertation module. The method stems from two different but related research areas. The first is described in section 2.2 and discusses topics such as thinking in reverse, customization and virtuality. The second is ICT-enabled business process reengineering being discussed in section 2.3. Hoogeweegen combined the ideas and viewpoints from these two research areas into one process modeling approach. The theoretical and empirical validation of this approach is the subject of this dissertation module. Section 2.4 discusses the research design and objective of this module, followed by an elaboration on the necessary demarcations of this research effort.

### *2.2 Thinking in reverse, customization and virtuality*

Conventional forms of organizations no longer seem to apply while they cannot live up to the growing heterogeneity of customer demand. They fail to fill the gap between what a company is offering and what a customer truly desires. Their underlying marketing thinking was based on the view that customers could be thought of as member of a homogeneous group. Statistical techniques then were applicable to understand and predict the behavior of such a group in accordance to meet their demand. Despite the ever-evolving richness and sophistication of these techniques (such as data-mining), combined with exhaustive databases filled with customer data, one still is not able to adequately predict individual behavior and most likely won't ever be (Zeleny 1996, van Asseldonk 1998). Many authors (e.g., Jarvenpaa & Ives 1994) claim therefore that we should try to think 'in reverse': take the actually expressed customer requirement as starting point for engineering or building the product or service. In other words, use a make-to-order philosophy instead of a make-to-sell orientation. When we do this, we no longer have to predict behavior while it actually occurs right in front of us.

Many new business models and (inter-) organizational forms have emerged in the past decade, which partly incorporate this new way of thinking. These include, among others, the virtual corporation (Davidow & Malone 1992), the boundaryless organization (Hirschorn & Gilmore 1992), the network-organization (Ching et al. 1996), the machine adhocracy (Bowman & Carter 1995), the value constellation (Normann & Ramírez 1993), the dynamic network (Miles & Snow 1986, 1992 and Jarvenpaa & Ives 1994), the agile enterprise (Goldman, Nagel & Preiss 1995), the virtual value chain (Rayport & Sviokla 1995, Benjamin & Wigand 1995) and the platform organization (Ciborra 1996). We will discuss these models by focusing on the former – the virtual corporation – while this is the business model that received the most attention recently by academics and practitioners, as is illustrated by the myriad of authors that have tried to define and describe the virtual organization (see table 2.1).

| Reference | Definition / Description |
|---|---|
| **Davidow & Malone (1992)** | Refer to a virtual corporation as based on the production of a virtual product as 'edgeless companies, with permeable and continuously changing interfaces between company, suppliers and customers […] for the cost-effective instantaneous production of mass-customized goods and services.' (p. 4-5) |
| **Byrne et al. (1993)** | '… a temporary network of independent companies – suppliers, customers, even erstwhile rivals - linked by information technology to share skills, costs, and access to one another's markets. It will have neither central office nor organization chart. It will have no hierarchy, no vertical integration.' (p. 37) |
| **Englman (1993)** | '…organizations form temporary partnerships in which each participating company brings to the table its core capabilities' (p. 28) |
| **Wexler (1993)** | '… (1) an association of employees not united at all times by a physical work environment; (2) an association of different companies able to come together temporarily through benefit of communications technology to achieve a common mission' (p. 97). |
| **Alexander (1997)** | Refers to the innovative management of organization boundaries, both in terms of 'lack of physical proximity' and 'lack of ownership' (p. 122) |
| **Eicher (1997)** | Refers to individuals, systems, resources, capital, and equipment focused on a finite task, project, or service. After the task, project, or service is completed, the virtual group disbands, going off to another virtual assignment (p. 6) |
| **Hardwick & Bolton (1997)** | '… is a temporary consortium of independent member companies coming together to quickly exploit fast-changing worldwide product manufacturing opportunities' (p. 59). |
| **Mowshowitz (1997b)** | A set of principles for metamanaging goal-oriented activities based on a categorical split between task requirements and their satisfiers (p.32) |

**Table 2.1: Definitions of virtual organization**

The versatility of these definitions illustrates the observation of Mowshowitz (1997a:32) that the virtual organization '… lacks a universally accepted definition, lying as it does at the confluence of several intellectual streams fed by reflection on computers and their applications'. Most of these definitions have strong similarities with the other emerging business models mentioned in the beginning of this section. The numerous models and the myriad of definitions lead us to searching the most important features and aspects of the new organizational forms. Recurrent key features in the terms and definitions are: temporary alignments of a network of independent organizations, dynamic switching between network partners, end-customer requirements as starting point, bringing together the core competencies of the partners and intensive use of ICT. Together, these features should be the enablers for reaching various business objectives such as increased customer satisfaction, innovation, responsiveness and profitability.

A specific new business paradigm, which embodies the thinking-in-reverse philosophy, is mass-customization (Davis 1987, Pine 1993). It is an oxymoron combining the concepts of ‘mass production’ and 'customization'. Nowadays, most of the enterprises are still operating under a mass-production philosophy. This is a clear philosophy, based on economies of scale, standardization of products and parts, specialization of labor and even standardization of customer communication, distribution and service. Standardization enables further rationalization[1] of value creating processes and subsequently higher efficiency and profitability of the manufacturers. The efficiency of mass-production however is strongly dependent on the stability and control of the environment and all other business processes. When this control and stability fail to exist and customers can no longer be thought of as members of a homogeneous market group, mass production may no longer be the appropriate business model and companies may loose their competitive edge.

Mass-customization is a response to the notion of ‘segments of one’: the idea that every customer is his own market segment with its own specific requirements. One of the most clear definitions of mass-customization is given by (Hart 1996:13): ‘the use of flexible processes and organizational structures to produce varied and often individually customized products and services at the price of standardized, mass-produced alternatives’. One of the ways to customize products is modularity. The concept of modularity first arose in the 60’s (Starr 1965) focusing on product manufacturing and design. Because of the ascent of mass-customization and comparable new business models it gained renewed interest in the mid 90’s. Products are increasingly designed in a modular fashion, where specific modules are only added to the core product whenever the customer requires them. By constantly changing the combination and composition of the modules one can actually mass-customize products. Modularity also works for services, especially information-intensive services (Venkatraman & Henderson 1998). It is, for instance, possible to reuse various modules of news and information to construct a customized news service. The Internet further enables organizations to engage into two-way dynamic interactions with their customers to constantly adapt and improve their product according to the customer’s wishes.

From these observations it has become clear that no single company operates as if it were on an island. The relationships with manufacturers, suppliers, resellers and customers also need to be addressed, while they should be closely involved in the design process. Companies should focus on their entire value chain, not merely on individual capabilities (Fine 1998). A current trend is that companies (and their surrounding supply chain or network) themselves are becoming more modular too (Daft & Lewin 1993). Tully (1993) stated that ‘modular companies’ are flourishing in two industries that sell trendy products at a fast tempo: apparel and electronics. Nowadays, organizations in other industries are also becoming increasingly modular, such as financial markets, automotive and chemical industries (Baldwin & Clark 1997). The relationship between modular products on the one hand and modular processes and organizations on the other is the focal point of interest in this dissertation.

---

[1] Rationalization is the systematic analysis and consolidation of product lines to align them with long-term corporate goals (Anderson & Pine 1997)

## *2.3 ICT-Enabled Process Reengineering*

A lot of useful work in the area of redesigning business processes to increase profitability has been described in the Information Systems (IS) literature. In the late eighties and early nineties, almost at the same time, Davenport & Short (1990) as well as Hammer & Champy (1993) introduced the term Business Process Redesign or Business Process Reengineering (BPR). Focusing on business *processes* instead of *tasks,* they developed a methodology that demonstrates how organizations can reinvent themselves. Not incremental improvement but radical change, as they claimed, was the key to success. The authors realized that information technology plays a crucial role in reengineering; it *permits* organizations to reengineer. Shared databases, expert systems, telecommunication networks, decision support tools and more recently the Internet are well-known examples of such technologies.

From this point on BPR became *the* managerial *buzzword* and countless companies acknowledged their need to reengineer. It led to numerous academic studies and corporate reengineering projects. Initiated by the continuing demand for rigorous transformation, there has been a flood of BPR consultants and numerous methodologies, techniques and tools to support the reengineering effort. However, BPR projects hardly ever brought the success that was expected by its founders (Kettinger et al. 1997, Nissen 1998). The strongly advocated process "obliteration" of Hammer and Champy was criticized and the absoluteness of the BPR principles was dispelled as "myth". Empirical studies showed that most companies did not undertake the revolutionary approach of radical change, but instead, due to political, organizational and resource constraints, mostly took an evolutionary, incremental approach (Kettinger et al. 1997, Sethi & King 1997).

With almost a decade of BPR practice, the area now has come to its third generation. Third generation BPR research tries to build on the evidence gained in many firms, in myriad settings with various business processes and using many different BPR approaches (Sethi & King 1997[2]). BPR is increasingly recognized as a form of organizational change, still with its primary focus on the business *process*. The goal of process transformation includes improved process products and services, measured in terms of cost, quality, customer satisfaction and shareholder value.

Despite the maturation of BPR, relatively little work has been carried out that explicitly focuses on the interorganizational process level. Venkatraman (1994) takes the capabilities of ICT as starting point and claims that the range of potential benefits from ICT is positively correlated with the degree of business transformation as is shown in figure 2.1:

[2] Sethi & King (1997) define the 'need of the original writers to publish books that were also largely based on their own experiences' as the second generation. Nissen (1998) on the other hand considers the redesign of the process of process redesign itself as the second BPR generation.

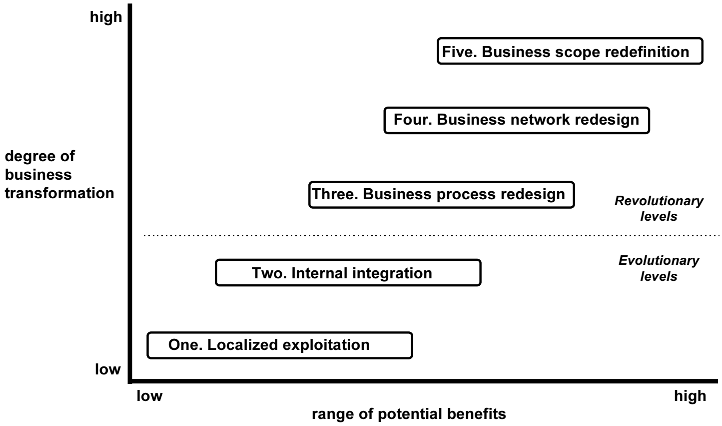


**Figure 2.1: Five levels of ICT-enabled business transformation (Venkatraman 1994)**

The central underlying thesis is that the benefits from ICT deployment are marginal if only superimposed on existing organizational conditions. Higher levels of transformation indicate potentially greater benefits, but they also require correspondingly higher degree of changes in organizational routines. The first revolutionary level, BPR, is limited to internal processes. The BNR level represents the redesign of the nature of exchange among multiple participants in a business network. The scope is extended beyond the organizational perspective of process innovation towards assessment of the complete structure of the network. The changes of the firms' roles and relationships to other actors in the business network and the strategic implication for all players are subject of study. In the literature of the mid-90's, only a few other examples can be found of methods and frameworks to analyze and support the redesign of business networks (Kambil & Short 1994, Henderson & Venkatraman 1993). Only recently, with the introduction of new information technologies (mobile intelligent agents, electronic commerce etc.) one really starts to consider interorganizational process redesign (Nissen 1998).

## *2.4 Research Design*

### 2.4.1 Research Objective

Only few studies can be found that actually combine BNR (or even BPR) research with the previously discussed customization or 'thinking in reverse' perspectives. Kettinger et al. (1997) give a broad and extensive overview of BPR methodologies, tools and techniques (MTTs) that have been developed in the past decade. They introduce a stage-activity framework that can be used to map and classify all the MTTs. According to Kettinger et al. (1997), planners can actually select the right MTTs to customize their own BPR project plan based on this BPR methodological framework. The specific choice should depend on four project characteristics, i.e. project radicalness, process structuredness, customer focus and potential for IT enablement. Although Kettinger et al. (1997) include customer focus as one of the four contingencies no link is made with any of the new business paradigms, such as mass-customization, agility or 'thinking in reverse'. New business *elixirs* such as E-commerce and the Internet are not mentioned by Kettinger et al. (1997) either.

Venkatraman & Henderson (1998) also note this problem by stating that process reengineering mainly focused on improved operating margins, while the focus has shifted towards process outsourcing. "Corporations are increasingly relying on external sources, positioning themselves in a network of resources where they acquire complementary capabilities." (Venkatraman & Henderson 1998). Because this combination of BNR and mass-customization/thinking-in-reverse has hardly been investigated, even though the combination seems obvious and prosperous, we will go deeper into this topic within this dissertation, taking the process modeling approach Modular Network Design (MND) as our starting point.

MND has been developed by Martijn Hoogeweegen (Hoogeweegen 1997). The approach tries to support BNR initiatives from a mass-customization perspective. It actually combines viewpoints from the BPR/BNR literature with the ideas from mass-customization and the thinking-in-reverse philosophy. The initial objective for designing Modular Network Design was to assess the impact of Electronic Data Interchange (EDI) on supply chain level. Hoogeweegen's central research question was how EDI-enabled alternative supply chain designs can be assessed concerning improvements in process costs and flexibility of the chain participants. The model combines quantitative assessment techniques, such as Activity Based Costing, with a specific (prescriptive) view on how networks of organizations should (re-) engineer their business processes. This view builds forth on the concepts of mass-customization, thinking in reverse and virtuality as discussed in section 2.2 and it further incorporates the concept of modularity which Pine et al. (1993) describe as *the* requirement for mass-customization. MND will be explained in full detail in chapter two.

As mentioned above, within this dissertation module we have taken the MND model as starting point of our analysis on the use of modularity in a business setting. The objective of this module is to analyze to what extent and under what circumstances the current MND model is applicable in supporting the design of customized and cost-efficient organizational networks. This effort will therefore not be aimed at the assessment of EDI investments specifically, as Hoogeweegen did, but will concern the evaluation and validation of the MND model itself. We hereby focus on two different aspects of the model, i.e. the descriptive and the prescriptive part of MND. Bosman (1986) distinguishes between these two aspects when he discusses theories and models for designing information systems. He further distinguishes between empirical and conceptual theories and models.

### 2.4.2 Research Questions

To achieve the previously formulated objective, i.e., validating the ability of the MND model to support the (re-) design of customized and flexible business networks, a number of questions are formulated. First, one central research question is asked, followed by a number of sub-questions on the two design perspectives of MND, its objectives and possible application areas.

The central research question is formulated as follows:
**How and to what extent does MND support the design of customized cost-efficient business networks?**

Formulated sub-questions are:
**What do we mean by customized cost-efficient business networks?**
**What type of support is required for designing these networks?**
**What type of design model is MND?**
**What are the strengths and weaknesses of MND?**
**Under what circumstances is the use of MND most useful?**
**How can MND possibly be enhanced to improve its contribution?**

To answer these questions we had to come up with a way to validate the applicability of the approach. For this purpose, a so-called validation framework has been constructed which consists of numerous variables that need to be addressed to analyze the validity of the approach. The research method used to 'fill in' the framework is described in the next section, while the actual validation framework itself is presented at the end of chapter 3, following the description on Modular Network Design itself and a number of other studies and theories on validation and decision support.

### 2.4.3 Research Method

Within this dissertation, the empirical cycle of conducting research plays a central role. It has been our guideline for setting up the research and structure its execution. The empirical cycle has been developed by the logical positivists (de Groot 1969, Runkel & McGrath 1972). They are led by a very strict normative view on how empirical scientific research should be conducted, following a fixed plan of approach, called the *empirical cycle*. Within this view, a research process is regarded as a series of logically ordered choices (although often with a chronologically chaotic character). Those choices run from formulation of the problem, through design and execution of the study, to analysis of results and their interpretation. In more general terms, the empirical cycle consists of five phases (de Groot 1969). Phase 1 is the **Observation** phase. It consists of collection and grouping of empirical materials; and the (tentative) formation of hypotheses. Phase 2 is the **Induction** phase and consists of the formulation of hypotheses. Phase 3 is **Deduction** consisting of the derivation of specific consequences from the hypotheses, in the form of testable predictions. Phase 4 is **Testing** the hypotheses against new empirical materials, by way of checking whether or not the predictions are fulfilled. Phase 5 is the final **Evaluation** of the outcome of the testing procedure with respect to the hypotheses or theories stated, as well as with a view to subsequent, continued, or related investigations. This sequence draws on the strengths and weakness of inductive and deductive reasoning by using them at different stages of the empirical cycle.

Although the series of choices is logically ordered and the set of choices is systematically circular (one starts with a problem and ends with a problem), even if all goes well, one never arrives back at the exact starting point. Therefore, the empirical cycle should really be regarded as a series of spirals (McGrath 1982).

The starting point of our research is – remarkably enough – not the first phase of the empirical cycle, i.e. observation. We will start our analysis on business modularity with the deduction phase. While we continue the work from Hoogeweegen, we can make use of his experiences and findings. Hoogeweegen already took care of the first two phases, observation and induction, which led to Modular Network Design and its accompanying theoretical framework (the hypotheses). Although it may seem that Hoogeweegen did only perform the first two steps of the entire empirical cycle, this is not the case. For his research objective, assessing the impact of EDI, he performed all steps from observation to evaluation. One of his findings was the hypothesis that MND could be useful for more purposes than assessing EDI-impact only. This hypothesis is the start of our analysis.

As is appropriate during the deduction phase, we will need to derive specific consequences from the hypothesis, in the form of testable predictions. This is done in chapter 3. From a statistical point of view validation of these predictions ideally should be done in as many representative circumstances as possible. However, we are merely looking for analytical validation and generalization (Yin 1994), i.e. in which a previously developed theory (in our case, MND) is used as a template with which to compare the empirical results of the case study. In line with this argument we decided to return to the air cargo industry, the place where the impact of EDI was assessed by MND initially, for two reasons. First, the testing environment should not be too much different from the situation where the approach was initially developed to keep the number of changes to a minimum. Second, the air cargo industry is an industry where issues such as customization of services, flexible business networks, cost efficiency and lead-time optimization play an important role.

Within the empirical studies, MND was applied on a number of different chain formations, with several organizations involved. Two different research approaches then are appropriate: case study and action research. The former is most applicable when a contemporary phenomenon is studied in its natural setting, where the boundaries between the phenomenon and the context are not evident (Yin 1994). A case study inquiry relies on multiple sources of evidence and it benefits from the prior development of theoretical propositions to guide data collection and analysis. The researcher itself has little or no control over the situation under study. The research goes sequential through the phases of design, collection, analysis and report.

Action research is intended to have the dual outcomes of action (change) and research (understanding) (Dick 1993, de Vreede 1995). Action researchers participate or intervene in the phenomenon under study in order to apply a theory to practice and evaluate its worth (Argyris et al. 1985, Benbasat et al. 1987). It can be characterized as cyclic, participative, qualitative and reflexive (Argyris et al. 1985, Dick 1993). The researcher follows different phases: planning, execution, observation, reflection and back to planning. This process is not sequential; the researcher may cycle through the phases regularly. Sometimes, action research is considered a subset of case study research (Galliers 1991). De Vreede (1995) indicates the following differences between case study and action research:

| **Case study** | **Action research** |
|---|---|
| Researcher is observer | Researcher is active participant |
| Exploratory, explanatory or descriptive | Prescriptive, intervening |
| Focus on ‘how?’ and ‘why?’ | Additional focus on ‘how to?’ |
| Possibly positivistic | Interpretivist |

**Table 2.2: Differences between case study and action research (de Vreede 1995)**

Case study research tends to be more objective than action research. The latter focuses on actually designing the processes in the situation studied (de Vreede 1995). In fact, both case studies and action research studies are theoretical extremes. Between the pure forms of case study and action research, a continuum of participation levels exists, based on the actual *level of participation* of the researcher. Zero participation is characteristic for a case study, full participation for action research. The reality of most empirical studies is probably somewhere in the middle.

Our study tends to be more an action research approach than a case study, while the researcher himself needed to actively participate in the application of the model. The researcher also tried to intervene in the business practice of the organizations involved by supporting the redesign of their business processes. Therefore, the researcher was able to influence the outcomes of the study directly. Although action research is sometimes seen as a mere excuse for consultancy (de Vreede 1995), this study aimed at carrying out scientific reflection on the applied model in order to validate and improve it.

### 2.4.4 Research Protocol

Because of its high participatory level a pre-defined protocol is hard to give for an action research based study. Nevertheless, the following plan of approach, denoted as business analysis protocol, will be followed as much as possible during the empirical studies. It is a cyclic approach starting with the intention of one or more organizations, which would like to have their processes analyzed with MND. When the analysis of the current situation has been carried out, the stakeholders can define a number of scenarios. These scenarios will be analyzed, next to possible other scenarios defined by the MND researcher itself, based on MND-related redesign guidelines, for instance. All scenarios will be compared after which the decision-maker may decide either to implement the best one or to define additional scenarios. In the latter situation, the cycle of analysis starts all over again. The protocol is depicted in figure 2.2 below. The dashed line in the middle indicates the separation between the decision-maker (above the line) and the MND-researcher (below).

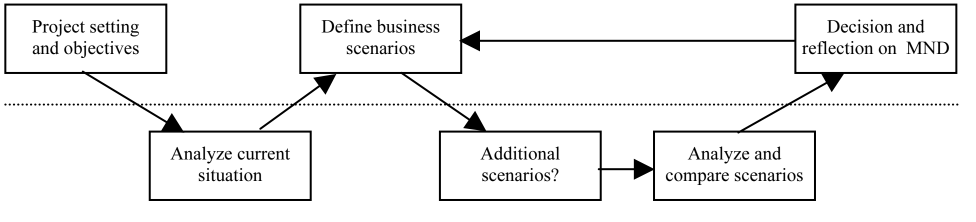


**Figure 2.2: Business analysis protocol**

### 2.4.5 Decision-making and bounded rationality

MND focuses on supporting organizational decision-making and solving organizational problems. Each discussion or statement about analyzing or solving organizational problems and decisions is implicitly (or explicitly) closely related to discussions or statements about rationality (Bosman 1986). Each solution to a problem assumes there is a problem description, one or more solutions to the problem and one or more criteria to make judgements about these possible solutions. The choice of these criteria and the way they are treated assumes a certain degree or type of rationality. Bosman (1986) discusses three of these types, also called paradigms:

1. infinite rationality, commonly used in economics and operations research
2. average or modal rationality
3. bounded rationality

Most of the tools of modern operations research - not only linear programming, but also integer programming, queuing theory and other widely used techniques - use the assumptions of SEU (subjective expected utility) theory (Simon 1986). SEU theory defines the conditions of perfect utility-maximizing rationality in a world of certainty or in a world in which the probability distributions of all relevant variables can be provided by the decision-makers. It assumes that what is desired is to maximize the achievement of some goal, under specified constraints and assuming that all alternatives and consequences (or their probability distributions) are known. These tools have proven their usefulness in a variety of applications.

Although not explicitly formulated as such, MND has been developed from the paradigm of bounded rationality (Simon 1982). Basically, the argument of bounded rationality is that limitations of human information processing do not allow decision-makers to operate in a truly "rational" manner, and that decision-makers therefore adopt strategies that maximize their chances of making a good decision, even though that strategy may not be optimal in a totally rational sense. The essence of this paradigm is the necessity for the decision-maker to have a description of the current situation first. The, generally accepted, three-step decision making model of Simon looks as follows:
Step 1 = envision, initiate
Step 2 = problem formulation, definition of alternatives, comparison of alternatives
Step 3 = choice, decision, implementation.

If we assumed full rationality, a decision-maker would only have to make the third step of choosing the best alternative because of its full knowledge. However, under bounded rationality the first two steps are also involved in the decision-making process. Decision support systems (DSS), expert systems, data warehousing etc. could support this process of searching for the best alternative. Usually however, they merely focus on supporting the third step, the actual choice. It may be argued that Modular Network Design could be grouped under these systems as well, thus with a mere focus on the step of choosing the best alternative. However, perhaps MND may be useful in the first two steps as well. To what extent this is true and this classification is useful, will be discussed in section 3.5.

### 2.4.6 Unit of analysis

The unit of analysis of this dissertation is the interorganizational network or value chain[3], which also means that ICT applications are studied that cross organizational borders, such as EDI, the Internet, Extranets or other Interorganizational Information Systems. While we

[3] We do not explicitly distinguish between a supply (or value) chain and an interorganizational network. Instead we speak of networked supply chains and regard a supply chain as the corporation plus its supply network, its distribution network and its alliance network (Fine 1996, van Asseldonk 1996). Both terms will thus be used alternately.

‘think in reverse’ and place the end-customer in the focal point of attention we include the end-customer(s) of the organizational network in our analysis as well.

## *2.5 Dissertation Module Structure*

The remainder of this dissertation module is structured as follows. While MND is the starting point of this module, chapter three has been dedicated to this modeling approach. It describes the initial reasons for development and the actual modeling approach itself. The chapter also discusses the likely position of MND in systems design theory, Decision Support Systems literature and the research area of Business Process Reengineering. The chapter is concluded with a validation framework that will be used to validate MND. Chapter 4 describes the process of validating MND. In this chapter the air cargo case studies are discussed together with the development of an MND-based Decision Support System, which was used during the two empirical studies. The module is concluded with discussing the answers to the research questions, validation of the research hypotheses, ways how MND may be improved and a number of possible research directions for the next research module of this dissertation.

# CHAPTER 3 MODULAR NETWORK DESIGN

## *3.1 Introduction*

At the Erasmus University Rotterdam[4] an ongoing research effort is taking place focusing on the organizational impact of changing business paradigms and new information and communication technologies (ICT). Assessing the business value of ICT, developing, analyzing and testing new business models and investigating new (electronic) price-setting and matching mechanisms (such as electronic auctions) are the essential elements of this research. As mentioned above, this module focuses on one specific new model called Modular Network Design (MND). MND has initially been developed by Martijn Hoogeweegen (Hoogeweegen 1997) to assess the impact of EDI on supply chain level. His central research question was how EDI-enabled alternative supply chain designs can be assessed concerning improvements in process costs and flexibility to the chain participants. During this research it became apparent that 'the MND approach should not be confined to EDI assessment only, but can become a new method for redesigning interorganizational processes' (Hoogeweegen 1997:xv). This statement has been the origin of the research effort described in this dissertation. The philosophy of MND is closely related to the new business paradigms discussed in section 2.2, such as mass-customization and virtual organizing. For instance, MND incorporates the concept of modularity which Pine et al. (1993) describe as *the* requirement for mass-customization. This justifies why MND has been taken as starting point of this thesis.

This chapter describes the background and development of MND. As mentioned in section 2.4.3, we start in the deduction phase from the empirical cycle of conducting research (de Groot 1969). This means that we try to derive specific consequences from the hypotheses formulated earlier in the cycle (during the induction phase), in the form of testable predictions. For a good overview, we therefore need to discuss the previous phases as well, although they were actually carried out by Hoogeweegen (1997). At the end of this chapter we will have arrived at a number of specific predictions about MND's ability to support the design of customized cost-efficient business networks.

Section 3.2 elaborates on the reasons to develop MND, followed by a description of MND as Hoogeweegen uses it in his thesis in section 3.3. The same section also contains some background information on a number of techniques, such as PERT (Program Evaluation and Review Technique)-diagramming and Activity Based Costing (ABC), which are incorporated in MND. Section 3.4 contains an overview of three different research areas which helps us in better characterizing and positioning MND: systems design theory, decision support systems and business reengineering. Section 3.5 finally contains the validation framework that has been defined based on the work of Hoogeweegen and related work of others, consisting of a number of specific (testable) criteria to evaluate the validity of MND within a redesign project.

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[4] In particular, the research program entitled Business Processes, Logistics and Information Systems at the department of Decision and Information Sciences of the faculty of Business Administration.

## *3.2 Background*

It was noticed in the second half of the 1990's that many organizations were still reluctant to implement EDI, despite the often-mentioned expected benefits such as reduction in inventory and communication costs. EDI is generically defined as "computer-to-computer exchange of standard business documentation in machine processable form" (Emmelhainz 1993). Some other definitions of EDI state that no human intervention is needed in the computer-to-computer exchange of business information. Other definitions have stated the EDI is transmission of business data between organizations in a computerized format that does not require the re-keying of information, since the EDI acronym has also been interpreted as Electronic Document Interchange. EDI is a central portion of the overall concept of Electronic Commerce. An important difference to e-mail and fax is that information exchanged with EDI is highly structured.

Only around 6% of all Dutch companies were using EDI in 1997 and Oakie (1997) reported approximately the same percentage in the US. A more recent study, undertaken by Trauth et al. (1998) indicates that the Netherlands are still falling short of expectations with respect to the diffusion of EDI. Andersen et al. (1999) have estimated that the unrealized potential for EDI use in business and industry is more than 80%. Iacovou et al. (1995) carried out a study in small and medium-sized enterprises to explain the reluctance towards EDI implementation. They identified three major factors that influence the EDI adoption decision: perceived benefits, organizational readiness and external pressure. Promotional efforts, financial and technological assistance and coercive tactics were recommended to EDI initiators by Iacovou et al. (1995) to assist them in preparing their partners expansion plans. The model has been empirically tested in a later stage by, among others, Chwelos et al. (1997) and Van Heck & Ribbers (1999). Just as Kaefer & Bendoly (2000), Hoogeweegen concentrates on the first of the mentioned factors by Iacovou et al.: perceived benefits. He proposes a method to assess EDI implementation proposals, assuming that application of the method would allow the management of an organization to perceive EDI benefits more accurately, thus supporting the adoption decision.

The method not only needed to demonstrate the benefits of EDI for one single organization but it should address the division of the benefits among all supply chain partners. A supply chain can be defined as a network of firms interacting to deliver a product or service to the end customer; linking flows from raw material supply to final delivery (Ellram 1991). The reason for Hoogeweegen to focus on the entire supply chain, instead of on the dyad-, industry- or network-level is twofold. First of all, Hoogeweegen states that the concepts of mass customization (Davis 1987, Pine 1993), 'customization-responsiveness squeeze' (McCutcheon 1994) and 'flexible service offerings' (Anderson & Narus 1995) mainly '… refer to how *single organizations* should increase their flexibility to meet the trend of customization, while keeping costs and throughput times low. The concepts, therefore, are based on the assumption that organizations do incorporate the four main business functions to customize, introduced by Lampel & Mintzberg (1996)' (Hoogeweegen 1997:2). Hoogeweegen refers in this respect to the functions design, fabrication, assembly and distribution. 'When an organization does not incorporate these four main business functions, it has to cooperate within its supply chain with trading partners to achieve the required level of flexibility' (Hoogeweegen 1997:3). The second reason to focus on the supply chain is based on the reasoning of Venkatraman (1994) that the higher the degree of business transformation, the higher the range of potential benefits from IT will be. Hoogeweegen refers to the notion of Business Network Redesign, 'which aims at the use of EDI to optimize the performance of all organizations involved in an EDI implementation project by considering how internal processes can be redesigned and how activities can be best distributed among the organizations to optimize total performance' (Hoogeweegen 1997:38-39).

Hoogeweegen denotes this improved chain performance, enabled by EDI, as 'cost efficient supply chain flexibility', reflecting upon the trend that supply chains are challenged to tailor their products and services to the specific requirements of every individual customer. Faster, more reliable and unambiguous communication between chain partners is a requisite to turn supply chains into flexible and responsive systems, without increasing the cost of producing the product or service. The use of EDI could enable this improved communication. Hoogeweegen then defines seven generic IT and EDI-based redesign guidelines:

1. Support information storage and processing;
2. Automate information exchange (internal and external);
3. Reduce human labor in a process;
4. Treat geographically dispersed resources as though they were centralized;
5. Execute processes simultaneously;
6. Put the decision point where the work is performed, and build control into the process;
7. Re-allocate activities among organizations.

Hoogeweegen also introduces the concept of the temporary supply chain (TSC), in line with the concepts of dynamic networking (Miles & Snow 1986, 1992), virtual organizing (Davidow & Malone 1992) and 'thinking in reverse' (Jarvenpaa & Ives 1994). The temporary supply chain '…consists of a number of organizations which coordinate their activities specifically for the fulfillment of one single customer order; after fulfillment, the temporary supply chain will be dissolved, and the organizations are ready to form new temporary supply chains' (Hoogeweegen 1997:22). A special role within the TSC is reserved for the temporary supply chain coordinator (TSCC). The TSCC is the organization which has received the customer order, and which is responsible for the fulfillment of that particular order (Hoogeweegen 1997:23). Any member of the organizational network can become TSCC by acquiring the order, after which it has to determine which other organizations it wants to sub-contract to participate in the order fulfillment, according to Hoogeweegen.

## *3.3 Description of MND*

### 3.3.1 Process modeling

Hoogeweegen introduces MND[5] to visualize and quantify the effects of EDI-enabled process redesign options. Hoogeweegen bases his choice for process modeling on the arguments of Ould (1995), who states there are three main purposes for modeling processes:

[5] Modular Network Design was initially named Modular Design Approach (Hoogeweegen et al. 1996)

1. To describe a process
2. To analyze a process
3. To enact a process

Three main directions in modeling techniques were available: simulation, diagramming and formal techniques. Hoogeweegen chooses to use a diagramming technique while this type of technique is most applicable to visualize changed process designs. The chosen technique is called Program Evaluation and Review Technique (PERT)-diagramming. Since its introduction in the 1950's, PERT-charts have been frequently used for planning and controlling projects in many different areas such as research and development, production, maintenance and others (Wiest & Levy 1977). The most important aspect of the technique is the Critical Path Method (CPM). In the PERT approach, the path with the longest (expected) duration is chosen as the critical path. The duration of activities lying on the critical path cannot be extended without extending the duration of the entire project.

### 3.3.2 Assessing costs and flexibility

Using PERT one is able to calculate the costs of the total project in function of its duration. To carry out the cost calculations one needs to know or estimate the actual costs of each activity. Hoogeweegen uses the Activity Based Costing (ABC) technique (Cooper 1988, Turney 1991) for this purpose. ABC is a tool for cost management. Activity based management seeks to portray a company as a series of activities which are related to customer desires and cost. ABC is a process for measuring the cost of the activities of an organization. Activities within an organization are identified and an average cost is associated with each activity. The total cost of a product is the sum of the costs of activities required to bring forth, sustain, and retire the product. The cost of an activity for a product is defined as the average cost of the activity times the number of times the activity is required for that product. Hoogeweegen distinguishes between two types of costs: operating and transaction costs. Indirect costs (such as overhead, insurance, depreciation and miscellaneous manufacturing salaries) are omitted from the analysis.

The modeling technique should also be able to assess the impact of EDI on the degree of flexibility of the entire supply chain and its individual partners. With respect to measuring the degree of flexibility, Hoogeweegen uses the work of Evans (1991), Bahrami (1992) and Volberda (1996). The type of flexibility most in line with the trend towards customization is Volberda's strategic flexibility, consisting of '… managerial capabilities related to the goals of the organization or the environment, necessary when the organization faces unfamiliar changes that have far-reaching consequences and needs to respond quickly' (Volberda 1996:363). Evans (1991) and Bahrami (1992) define four archetypal maneuvers as a means to attain strategic flexibility of which the ex ante, offensive maneuver is most applicable. It includes agility and versatility as the two abilities that an organization should possess to attain this type of strategic flexibility.

| | Ex ante | Ex post |
|---|---|---|
| **Offense** | Agility<br>Versatility | Liquidity<br>Elasticity |
| **Defense** | Robustness<br>Hedging | Corrigibility<br>Resilience |

**Figure 3.1: Strategic flexibility (Evans 1991)**

Hoogeweegen formulates the following definitions of agility and versatility. Agility refers to the period of time it takes for a system to fulfil a customer order. This period starts with the placement of the order and terminates when the order has been fulfilled. Versatility refers to the extensiveness of a product and/or service range a system is able to deliver both in terms of the variety of products and service (external versatility) and the number of options available to produce specific products or services (internal versatility) (Hoogeweegen 1997:27).

### 3.3.3 Modeling Elements

As mentioned above, MND was developed to visualize the process of order taking, process and organization selection and the computation of costs and throughput time of order fulfillment. To accomplish this, four modeling elements are introduced: service elements, production elements, process modules and process module networks (Hoogeweegen 1997:61). We will describe the modeling steps of MND based on the concept of metamanagement as developed by Mowshowitz (1997a&b). It is a suitable guideline to follow the reasoning of Hoogeweegen, although he actually was unaware of this concept when developing MND. Only in a later stage, the link between metamanagement and MND was made by Wolters & Hoogeweegen (2000).

Mowshowitz (1997b) introduces metamanagement as a means to structure and to manage the goal-oriented activities of a virtual organization. Metamanagement consists of four basic activities:

1. analyzing abstract requirements;
2. tracking the possibilities for satisfying requirements;
3. developing and maintaining the procedure for assigning (or allocating) satisfiers to requirements;
4. adjusting the optimality (or ‘satisficing’) criteria of the allocation procedure.

Requirements refer to the logically defined needs of a task. Making a product, for example, requires raw materials, tools and labor. Each of these requirements may be viewed as an abstract need, in the sense that it can be met in a variety of ways. The particular ways in which a requirement can be met constitute concrete satisfiers (Mowshowitz 1997a:374). According to Mowshowitz, the essence of a virtual organization is to dynamically switch from one supplier to another, based on changing opportunities in the marketplace. Mowshowitz argues that new management activities are needed to organize activity virtually, which in essence comes to ‘analyze abstract requirements and to track concrete satisfiers’ (Mowshowitz 1997a:379).

Metamanagement requires standardized organizational structure and behavior to achieve interchangeability and compatibility. A means to achieve this standardization and interchangeability is modularity. A modular approach intentionally tries to create a product or process design that permits the “substitution” of different versions of functional components for the purpose of creating product or process variations with different functionalities or performance levels (Sanchez 1997). It provides standardized organizational structures, enabling constant change of the product or service design in response to customer requests. Modular design avoids creating strong interdependencies among specific component designs and instead tries to create 'loosely coupled' component designs (Orton & Weick 1990).

MND is strongly based on the concept of modularity. Within MND, both the product and/or service range as well as the organizational activities are described in modules. The product and/or service range is described in service elements, while the activities are described in process modules. The generic procedure of is depicted in figure 3.2 and consists of four steps, analogous to the four steps of metamanagement of Mowshowitz (1997a). The MND procedure tries to operationalize the four steps of metamanagement. The four MND steps are:

1. Determination and analysis of customer requirements: service elements;
2. Tracking the possibilities to satisfy customer requirements: translation of service elements into production elements supplied by network partners;
3. Allocation of production elements among network partners: translation of production elements into a process module network;
4. Ongoing assessment and redesign of activities and allocation procedures.

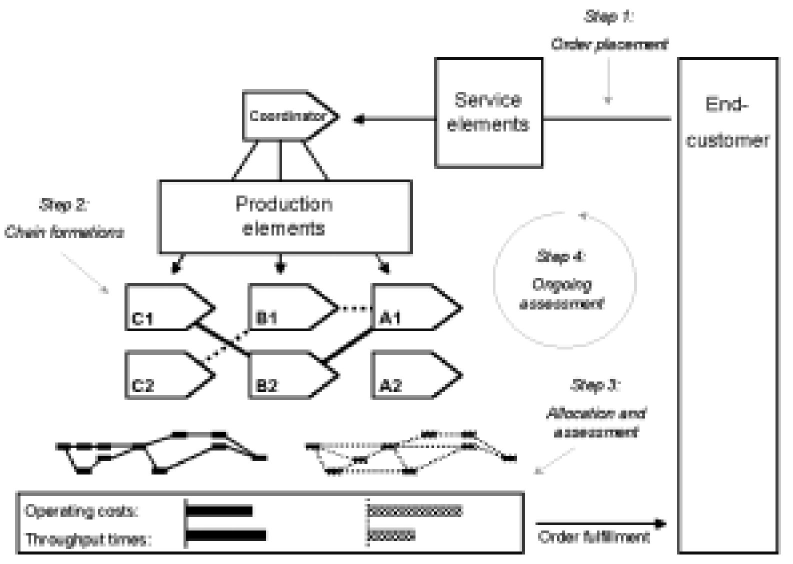


**Figure 3.2: The four steps of Modular Network Design**

The four steps are supported with a quantitative analysis and visualization of the production activities to compare different chain designs, or to evaluate opportunities for ICT use. Each of the steps is described in more detail below.

The first step of metamanagement concerns analyzing abstract requirements. Within MND abstract requirements are seen as specific features of the total product and/or service range offered by the network of organizations, called service elements. Either the customer specifies its requirements by selecting service elements from the available set or the network coordinator translates the incoming order in service elements. This network or supply chain coordinator as Hoogeweegen calls it, fulfills a special role. The organization that has required the order will become the coordinator, but only for the duration of the order. It is a temporary role. The temporary coordinator is responsible for the fulfillment of that particular order and it has to determine which other organizations will cooperate in the fulfillment of the order.

In different combinations, the service elements describe different types of orders. Whenever a customer requires a service element that is not available in the set, the coordinator should search for additional sub-contractors, able to fulfil this specific service element. Examples of service elements in manufacturing can especially be found in the computer and automotive industry where customers can actually design their own PC or car by specifying numerous features of the product. Logistics, travel and transportation are good examples of service industries that use the service element concept (see Lovelock 1992 for an illustration of Federal Express's use of service elements).

The second step of metamanagement concerns tracking the possibilities for satisfying requirements. Within MND this step is operationalized in the form of production elements. Production elements also describe specific features of the product and/or service range, but they are formulated in terms of production. Whereas service elements describe what customers see and may order, the production elements describe what a specific organization is able to produce. The coordinator searches for ways to translate the selected service elements into production elements. It determines possible chain formations based on the production elements offered by the possible sub-contractors of the coordinator. In figure 3.2 two possible formations are illustrated involving the organizations (C1, B2, A1; the solid line) and (C2, B1, A1; the dashed line). The number of feasible chain formations will depend on the number of available sub-contractors and on the degrees of freedom the coordinator has due to the customer's requirements and their restrictive influence on the design of the network. In general the more specific the customer requirements, the less degrees of freedom a coordinator has.

In the third step of metamanagement, the satisfiers need to be assigned to requirements. According to Mowshowitz (1997a), it is possible for management to switch from one sub-contractor to another to take advantage of dynamically changing opportunities in the marketplace. Cost and delivery or throughput times play an important role in these considerations. For this reason, the process module is introduced, as the lowest level of process activity, to support the participants in assessing their performance. A process module can be described as a standardized and not further divisible, process step, referring to either information processing or physical activities. Each sub-contractor translates their, generic, production elements into a set of process modules. Based on the dependencies, also called relationships, between the process modules for each possible formation a process module network can be designed. These networks indicate in what order the modules are executed to fulfill the customer order. For each of these networks operating and transaction costs are computed based on the Activity Based Costing technique, while throughput time is computed based on the Critical Path Method.

The fourth step of metamanagement concerns adjustment of the optimality (or 'satisficing') criteria of the allocation procedure. According to Mowshowitz, examining criteria and goals explicitly injects self-reflection in organizational life. The habit of self-reflection should be a regular feature of management behavior (Mowshowitz 1997a). Within MND this step has been operationalized as an ongoing assessment and reflection of all the previous steps. For instance, visualization of all business processes in process module networks could enable the detection of possible improvements and redesign options. MND may be used to compare different process module networks, which all refer to the fulfillment of the same set of service elements, but that use ICT applications, such as EDI or the Internet, or use ICT differently. Based on such a comparison, a decision whether to implement a specific ICT application can be supported through the assessment of its impact on process module network design, costs and throughput time. Furthermore, MND allows the coordinator to constantly evaluate the composition of its set of service elements, the way service elements are translated into production elements and last but not least, the composition of the network of sub-contractors. It may also support management in defining modules and their mutual interfaces.

### 3.3.4 Case studies in air cargo industry

Hoogeweegen carries out four case studies in the Dutch air cargo industry, which together form a multiple embedded case study. A multiple-embedded case study is a multiple case study, which involves more than one level of analysis (Yin 1994). The case studies are conducted for the following reasons:

1. To support organizations operating in the air cargo industry with the decision whether to implement EDI or not;
2. To test the applicability of the new modeling approach Modular Network Design;
3. To test the employability of the formulated seven EDI-based redesign guidelines;
4. To validate the research claim that EDI can be used to decrease the costs and at the same time increase flexibility.

In each case study the fulfillment of an export order, from order placement by the customer (in cargo terms the customer is called shipper) till the moment of departure of the plane from the air carrier's site, is subject of study. The following case study protocol is followed:

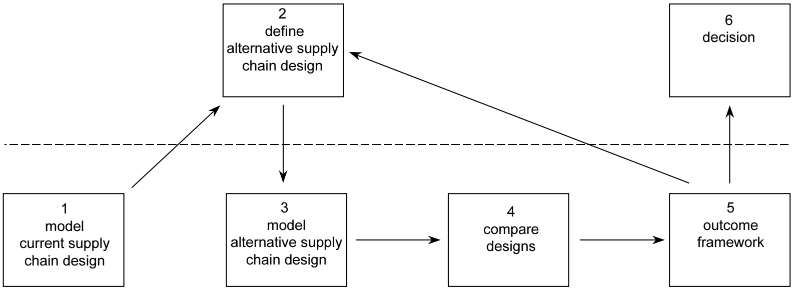


**Figure 3.3: Plan of approach**

Hoogeweegen concludes the following from his case studies with respect to the previous four questions.

1. Several of the BNR scenarios show that all parties could benefit from the introduction of EDI, however the benefits were not equally distributed, with respect to cost and time savings. This imbalance and other conflicting interests, especially between forwarders and air carriers, led to a strong reluctance to actually implement the scenarios.
2. Visualization with the process module networks provides sufficient insight in how EDI-enabled process redesign would look like. Moreover, the use of service elements, production elements and cost and time consumption of process modules offers the insight required verifying the different aspects of costs and flexibility of these new process designs.
3. The IT and EDI-based redesign guidelines need further testing and refinement to become sound redesign principles which business partners can apply easily.
4. According to Hoogeweegen EDI can indeed be used to increase the flexibility of a supply chain as well as lower its costs. It should however, be noted that the case studies at the air cargo industry in fact do not concern supply chains in the sense Hoogeweegen defines them at page 18 (after Scott & Westbrook 1991:23): 'the supply chain is linking each element of the production and supply process of products and services from suppliers to the end-customer'. The air cargo industry is by definition only involved in the transport & distribution part of an entire supply chain. The other stages, like design, manufacturing, assembly and sales, have been omitted from the analysis.

In his thesis, Hoogeweegen already mentions a number of limitations of MND and its application in the four case studies himself. These limitations are:

- All orders are analyzed individually. Therefore, order fulfillment restrictions caused by other orders in progress are not taken into account. Although orders are chosen that frequently occurred, one cannot calculate total savings by multiplying the single order savings by the total number of orders, according to Hoogeweegen.
- The analysis is restricted to the export part, at the airport of departure, of transport orders only.
- Possible errors and mistakes made during actual execution of the orders are excluded.
- The EDI scenarios are not tested for their technological or legal feasibility.
- Only direct costs are included; indirect costs were omitted from the analysis.
- The required investments (in EDI) to realize any of the redesign scenarios are not included.

## *3.4 Positioning MND*

Before our final validation model, to be used in the next empirical chapter to test our hypothesis, is presented in the next section, three research areas closely related to MND are discussed first. This overview of these other areas helps us to better characterize and position MND to support the definition of a good validation model to analyze the possible contribution and validity of MND. The following perspectives and directions are chosen in this section. The first concerns the framework of Bosman (1986) about systems design theory. This framework helps us in dividing MND into two parts, which need to be validated individually. The second is the research area focusing on Decision Support Systems. The third concerns the area of Business Process Redesign. The last two areas assist us in specifying the empirical descriptive part of MND, i.e. MND's contribution in offering decision support during interorganizational (re-) design projects by assessing several scenarios on the basis of a number of pre-specified criteria.

### 3.4.1 Systems design theory

In this section we return to the model of Bosman (1986, see also section 2.4.1) to better characterize MND. The framework is depicted in figure 3.4 below:

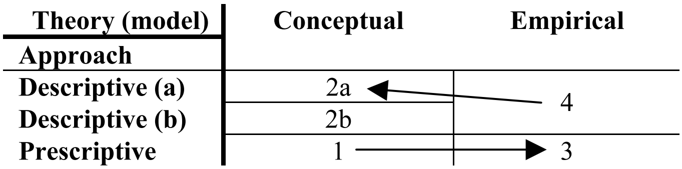


**Figure 3.4: A classification of design models (Bosman 1986)**

Bosman states that models and theories to support the design of systems, e.g., information systems, business processes or value chains, can be categorized in two directions. First, he distinguishes between conceptual and empirical models. The difference lies in the fact that conceptual theories are free of (empirical) data. They just specify the variables and their mutual relationships to describe and solve the problem at hand. Empirical models on the other hand, are built from empirical data and variables.

Furthermore, one can distinguish between descriptive and prescriptive models. Conceptual prescriptive theories offer a (generic) solution to the problem by using one or more algorithms and it must be possible to translate them in an empirical model (the arrow from cell 1 to 3). Empirical descriptive models (cell 4) on the other hand should possess an underlying conceptual descriptive model, while every description of 'something' is based on a conception (the arrow from cell 4 to 2a). Some conceptual theories are not suitable for translation in empirical models, e.g., because some variables of the model cannot be measured or the relationships between the variables cannot be determined. These theories are denoted as conceptual descriptive (cell 2b).

In the light of this framework of Bosman we observe that MND actually possesses both an empirical descriptive part (cell 4) as well as a conceptual prescriptive one (cell 1). The conceptual prescriptive part of MND consists of a number of design elements, introduced to prescribe organizations *how* they should design their processes and business structures. The design elements can be considered the algorithms of the conceptual prescriptive MND model. They are:

- Temporary alignments of organizations, only getting together for the duration of one particular customer order;
- Modular product, process and network design;
- Presence of a central coordinator responsible for the fulfillment of the customer order;

- Direct translation (or materialization) of customer requirements into production to optimize the balance between what a customer is asking and what a chain is able to produce.

The argument is that these design elements together could lead to an increase in the flexibility and responsiveness of value chains, in section 2.2 summarized as cost efficient customized value chains. In section 3.2, we already discussed these conceptual prescriptive elements of MND in more detail. The elements and their proposed mutual relationships are illustrated in figure 3.5.

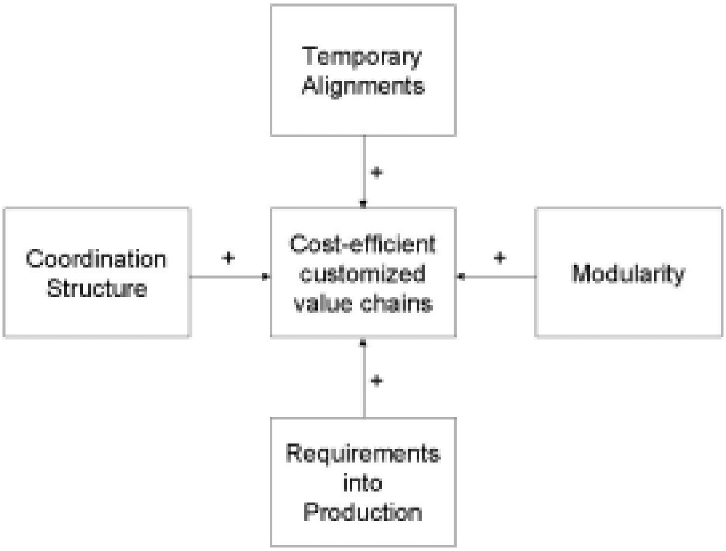


**Figure 3.5: Conceptual, prescriptive model of MND**

The empirical descriptive part is based on the initial reason of Hoogeweegen to develop MND, i.e. the assessment of EDI. For this reason MND was accommodated with a number of assessment techniques, such as activity based costing and the critical path method. Furthermore, attention was paid to the visualization of business processes by the means of the process module networks. Service and production elements were introduced to assess the degree of internal and external versatility of a value chain. In this manner, Hoogeweegen was able to determine the impact of EDI on supply chain flexibility. The elements of the empirical descriptive part of MND are depicted in figure 3.6 below.

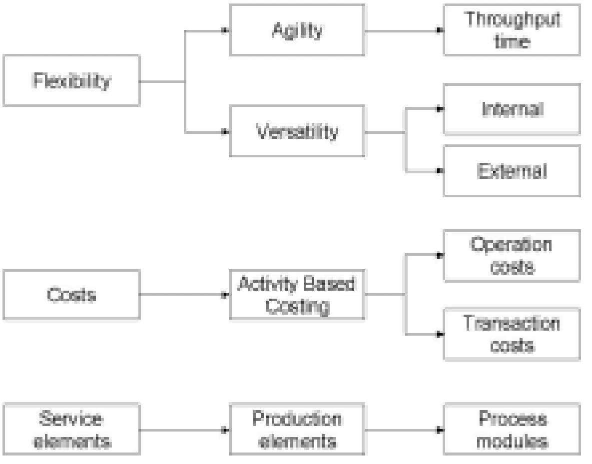


**Figure 3.6: Empirical descriptive part of MND**

The elements can be divided into three categories: flexibility, costs and the modeling/visualization elements. All of these have already been described in the sections 3.3.2 and 3.3.3, so we will not go deeper into them in this section.

Bosman argued that an empirical descriptive model should possess a conceptual part and that a conceptual prescriptive model should be translatable into an empirical model. To analyze the contribution of MND in supporting the design of cost-efficient, flexible value chains these two translations (the arrows in the Bosman framework) need therefore to be analyzed.

The first arrow (from cell 1 to cell 3 in figure 3.4) refers in this respect to the possibility (and usefulness) of translating the constructs used within MND, such as the temporary supply chain coordinator and the use of modularity, into empirically useful guidelines or methods. This will be the first part of our validation model: validate whether (and to what extent) the four (conceptual) MND constructs (see figure 3.5) are translatable into empirically useful guidelines. For each of these four constructs, it will be investigated whether this is indeed the case. In section 3.5, it is described exactly how this is done.

The second arrow (from 4 to 2a in figure 3.4) refers to the validity of the assessment and visualization techniques used in the empirical MND model. This means that we need to determine whether these methods are the right methods to analyze EDI investments or supply chain flexibility and whether the concepts flexibility, costs and impact have been adequately operationalized within the empirical model (see figure 3.6). This will be the second part of our validation model.

To further specify the latter part of the MND validation model we examine a number of related research fields, i.e. Decision Support Systems and Business Process Redesign. Both fields should help us in specifying the empirical part of the validation model.

### 3.4.2 Decision Support Systems

Research on Decision Support Systems (DSSs) more or less started in the 70's when the use of computers became common practice in organizations. DSSs support ill-structured decision situations. Alter (1977) defined a taxonomy of DSSs distinguishing between logic-oriented and data-oriented systems. Later, the human-computer interface was added to this classification scheme (see Panko 1988). Another dimension was added by Finlay & Wilson (1987), namely the system builder. In summary four different DSS components can be distinguished:

1. Logic model: the set of rules by which new information is calculated
2. Data model: the values given to variables, parameters and constants
3. Human-computer interface: the way the user interacts with the system
4. System builder: the person or team that built the system

Based on this taxonomy Finlay & Wilson (1997) developed a framework to validate Decision Support Systems. The relation between the DSS components and the validity framework is depicted below (figure 3.7):

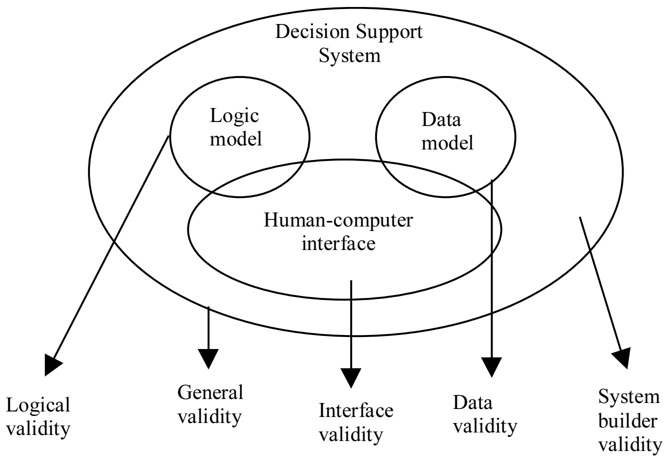


**Figure 3.7: DSS components and their validity (Finlay & Wilson 1997)**

For each of these five types of validity, Finlay & Wilson (1997) distinguish a number of sub-types of validity and they include face validity as an extra form of validity that is applicable to all aspects of a DSS. It is a superficial measure of the similarity of aspects of the system with information from other 'approved' sources. The framework is depicted below in figure 3.8.

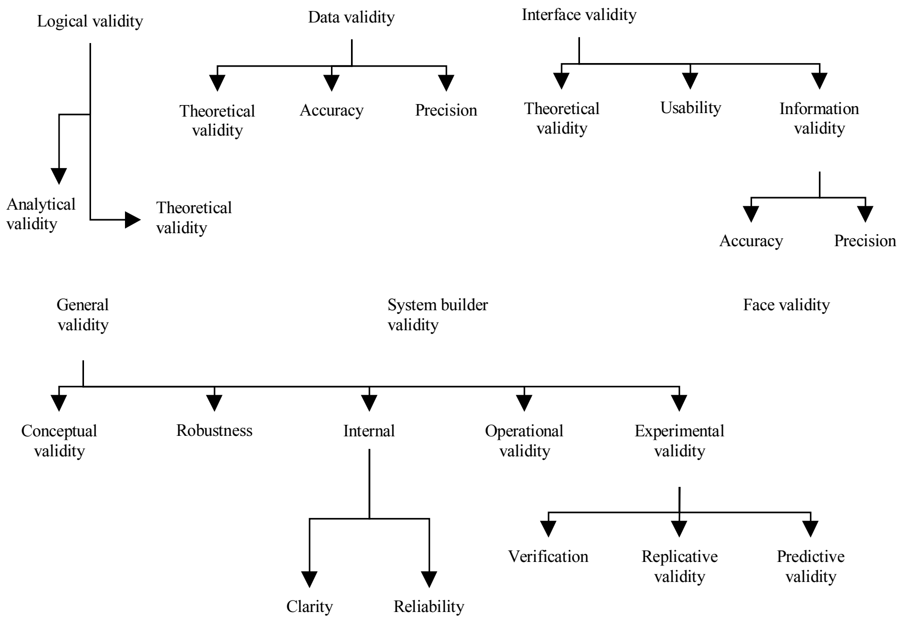


**Figure 3.8: Validity framework for a DSS (Finlay & Wilson 1997)**

The subsequent subtypes of each of the four main validity types are discussed below.

Logical validity consists of two different types:
- Analytical validity: A measure of the appropriateness of each individual relationship in the logic model treated separately.
- Theoretical validity: Whether the construction of the logic model can be justified in terms of established theory.

Data validity is divided in three different types:
- Accuracy: A measure of the systematic bias in a piece of data or information.
- Precision: A measure of the random error in a piece of data or information.
- Theoretical validity: Whether the construction of the data model can be justified in terms of established theory.

Interface validity consists of three sub-types:
- Theoretical validity: whether the construction of the human-computer interface can be justified in terms of established theory.
- Usability: the interaction between the user and the system proceeds as intended by the designer.
- Information validity: concerned with the accuracy and precision of the information available as output from the DSS.

Finlay & Wilson (1997) define the following sub-types of general validity:

- Conceptual validity: check whether the system as a whole is appropriate to use for the problem under investigation.
- Experimental validity: check whether the predictions or replications of the model actually are similar with information from other 'approved' sources. It includes predictive and replicative validity and verification.
- Internal validity: ensuring that causes and effects can be unambiguously identified, incorporating concerns about appropriately attributing meanings to information and involves issues of clarity and reliability.
- Robustness: the extent to which the model is usable in situations not expressly defined in the model's development, i.e. the range of applications of the model.
- Operational validity: a measure of the quality and applicability of the solutions and recommendations derived from the model with respect to the intended user and with respect to the problem situation.

System builder validity and face validity have no further sub-types.

The model of Finlay and Wilson (1997) is closely similar to the validation model of O'Leary (1987). He argues that the validation of a system must address a number of areas, including construct validity (similar to logical validity of Finlay & Wilson), content validity (data validity) and criterion validity (general validity).

The empirical descriptive part of MND actually is the part of MND that has been programmed into a Decision Support System. Therefore, the taxonomy should be applicable and enable a more detailed description of the model. Subsequently, we could apply the validity framework of Finlay & Wilson to validate the empirical descriptive MND in supporting the design of flexible, cost-efficient value chains. We will elaborate on each part of the DSS validation framework in respect to MND below.

The rules of the <u>logic model</u> - the set of rules by which new information is calculated - of MND (single order) are the following:

- Agility = critical time = sum of duration of all activities on the critical path
- Total time = sum of duration of all activities
- Cost of an activity = duration of the activity multiplied by the total resource costs per time unit
- Total costs = sum of individual costs of all activities
- External versatility = number of possible different combinations of service elements
- Internal versatility = number of different ways a selection of service elements can be translated into production elements[6].
- A logic to define the relationships between the service elements, production elements and process modules.

The <u>data model</u> consists of the empirically retrieved process data, required to make the calculations within the logic model. For MND this includes:

- The activities (process modules) required to execute a specific order
- The duration of all activities

[6] The criteria agility and versatility together make up the flexibility of a chain or network (Hoogeweegen 1997).

- The resources required to execute each activity
- The cost drivers of these activities
- The costs of using resources.
- The definition of the service elements and production elements.
- The organizations involved in the fulfillment of the order

The human-computer interface was developed for the program Erasmus in Chains. Visual Basic modules and Microsoft applications were used to make this interface as user-friendly as possible. The visualization of business processes in process module networks is the main component of the user interface. In addition, the way the other elements of MND, e.g., the service elements and the production elements, are entered into the system belong to the human-computer interface component. One practical remark however, must be made when MND is really placed in this framework. It concerns the issue of the end-user of the system. Up until now, the MND-based computer program, Erasmus in Chains, has not been installed or implemented within an organization. Therefore, we cannot speak of a typical end-user of the system, except for the researcher himself. This forces us to view interface validity from the viewpoint of the proposed end-user – managers from organizations who may be using the system in the future. Interface validity will therefore be changed to perceived interface validity.

Finally, the system builder of MND is obviously Hoogeweegen himself, together with a number of software programmers who built the program Erasmus in Chains.

Based on this summary we may conclude that the empirical descriptive part of MND can be compared with a DSS and therefore, the Finlay & Wilson framework can be used for our purpose. The DSS validation framework may be used for validating the empirical descriptive part of MND. In the previous section, it was argued that empirical descriptive models (cell 4) should possess an underlying conceptual descriptive model, while every description of 'something' is based on a conception (the arrow from cell 4 to 2a in figure 3.4). This means that we can use the framework of Finlay & Wilson to verify whether the empirical data and variables collected with MND are indeed legitimate operationalizations and measurements of (theoretical) concepts.

### 3.4.3 BPR methodologies, tools and techniques

In section 2.3, the topic of ICT-enabled Business Process Reengineering (BPR) was already discussed. This section elaborates on different methodologies, tools and techniques (MTTs), which could support organizations in their redesign efforts. The question is asked which type of BPR projects require which type of MTTs. The reason to do this, is to further specify the relationship between the business environment in which MND is applied and the characteristics of MND. That is, we not only need to be sure that within MND all variables are operationalized and measured correctly, we also need to ensure that the application of MND is justified. Is the BPR project at hand indeed suitable for applying MND or are other tools and techniques perhaps more useful? In other words studying the BPR literature helps us in determining the general validity of MND, in particular the conceptual validity and robustness of the model.

Kettinger et al. (1997) investigate numerous MTTs and discuss them in their article in MIS Quarterly. They develop a generic BPR project stage-activity framework, based on a study of 25 BPR methodologies, in which they distinguish the following stages and activities for business process change methodologies:

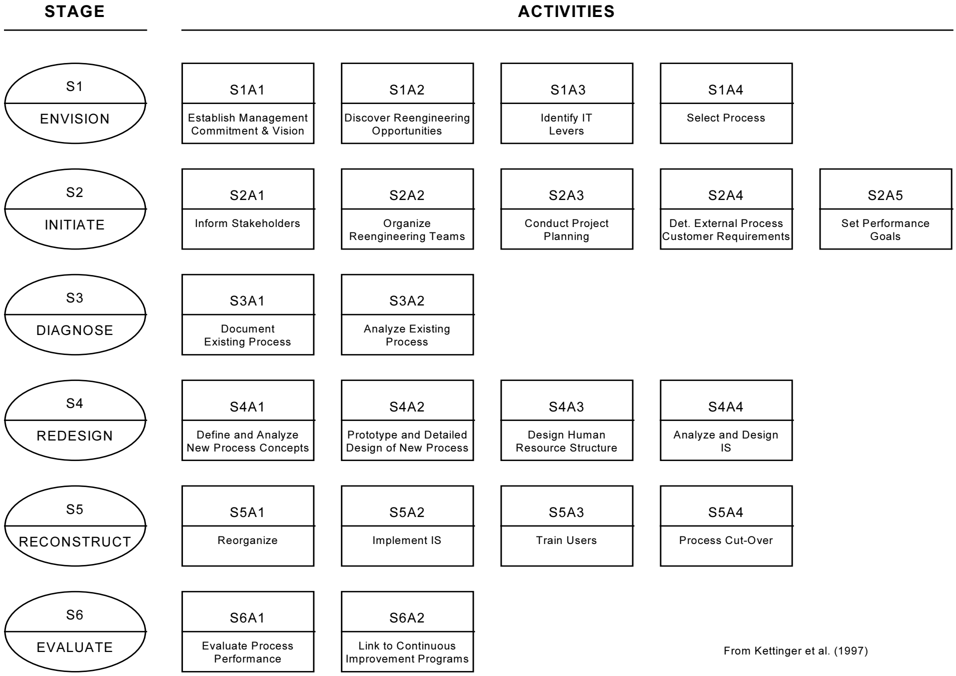


**Figure 3.9: Stage-activity BPR framework (Kettinger et al. 1997)**

Next, they map numerous BPR techniques and tools onto this framework and verify their support for each activity. Obviously MND can be mapped on this framework as well. Table 3.1 below depicts the mapping of the MND-related techniques as done by Kettinger et al. (1997).

| Stage | 1 | | | | 2 | | | | | 3 | | 4 | | | | 5 | | | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Activity** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **1** | **2** |
| **Activity Based Costing** | | | | | | | | | | ■ | ■ | | ■ | | | | | | | ■ | |
| **Brainstorming** | | ■ | ■ | | | | | | | | | ■ | | ■ | | | | | | | |
| **Data Flow Diagramming** | | | | | | | | | | ■ | | ■ | ■ | | ■ | | | | | | |
| **Hierarch. Colored Petri Nets** | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| **IDEF $_{0, 3, 6}$** | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| **IDEF $_{1, 1X, 4, 5}$** | | | | | | | | | | | | | | | ■ | | | | | | |
| **IDEF $_{2}$** | | | | | | | | | | | | ■ | ■ | | | | | | | | |
| **Information Technology Anal.** | | | ■ | | | | | | | | | | | | | | | | | | |
| **Process Flowcharting** | | | | | | | | | | ■ | | ■ | ■ | | | | | | | | |
| **Simulation** | | | | | | | | | | | | ■ | ■ | | | | | | | | |
| **Value-Chain Analysis** | | ■ | | | | | | | | | | | | | | | | | | | |

**Table 3.1: Mapping of BPR tools and techniques onto stage-activity framework (Kettinger et al. 1997)**

Several of these techniques perhaps need further explaining while they may be unknown to the reader. The Activity Based Costing technique determines how a process and its subprocesses consume resources by identifying cost drivers to activities (Turney 1991). Brainstorming provides an open forum for spontaneous generation of ideas from members of a group. Creative thinking is stimulated through a process of adding on the others' concepts. Data flow diagramming graphically depicts the flow of data among external entities, internal processing steps and data storage elements. Hierarchical Colored Petri Nets are a colored version of the traditional Petri-Net systems models, well-suited for portraying, simulating and analyzing large systems and processes. In Process Flowcharting typical flow charting symbols and methods are applied to depict the logic and flow of activities in a business process. Value-Chain Analysis was proposed by Porter & Millar (1985). This technique involves a systematic evaluation of the flow of a company's activities in terms of "value" (the extent to which buyers are willing to pay for a product or service). There are nine generic categories of a company's value activities. These can be classified as primary activities (inbound logistics, operation, marketing, etc.) and support activities (human resource, technology management, etc.).

Information Technology Analysis (ITA) is based on the work of Davenport and Short (1990). This technique is used to match IT capabilities to certain process reengineering requirements. Hoogeweegen (1997) also used the work of Davenport & Short (1990) to come up with seven generic IT redesign guidelines. These guidelines were already discussed in section 3.2 and will be further elaborated on in section 4.4.4. The following table illustrates the features of the ITA technique.

| Process Type | Typical BPR Requirements | Capabilities of the Enabling IT |
|---|---|---|
| Interorganizational processes (e.g., ordering from suppliers) | Transform unstructured processes into routinized transactions. | IT such as EDI and shared databases which lower transaction costs and eliminate intermediaries. |
| Interfunctional processes (e.g., new product development) | Transfer information rapidity across large distances. | IT such as CAD and WANs that support simultaneous work in different locations. |
| Interpersonal processes (e.g., approving a bank loan) | Remove intermediary and connect two parties within a process. | IT such as groupware and imaging that facilitate role and task integration. |
| Physical processes (e.g., manufacturing) | Reduce or replace human labor in a process. | IT such as CAM and robotics which increase outcome flexibility and process control. |
| Informational processes (e.g., creating a proposal) | Bring vast amounts of information into a process. | IT such as AI, multimedia and the WWW that provide unstructured information and routinize decision logic. |
| Operational processes (e.g., order processing) | Change the sequence of tasks and allow some tasks to be done simultaneously. | IT such as electronic commerce, workflow systems, and shared data bases that reduce time and cost and increase output quality. |
| Managerial processes (e.g., budget preparation) | Bring complex analytical methods to bear on a process | IT such as expert systems and EIS that improve analysis and increase participation. |

**Table 3.2: IT/Process Analysis (Davenport & Short 1990)**

Finally, IDEF is a systems analysis and design methodology established by US Air Force as a result of its Integrated Computer and Manufacturing (ICAM) program. $IDEF_0$ is an activity modeling module for capturing functional requirements. $IDEF_3$ incorporates the time dimension to capture the behavior of objects in the enterprise through state-transition diagrams. $IDEF_6$ captures “meta designs” i.e., the knowledge and thinking that went into framing the other IDEF modules. $IDEF_1$ is the data-modeling module using the entity relationship diagramming method. $IDEF_4$ deals with object-oriented data modeling. $IDEF_5$ provides a repository for large analysis and design information. $IDEF_2$ is the IDEF module that provides simulation of the process to depict its dynamic behavior and how information and resources in the organization are used (Mayer et al., 1995)

In the same article Kettinger et al. (1997) develop a contingency approach usable to select the best tools and techniques in relation with the characteristics of the redesign project. Four different project characteristics are defined:

- Project radicalness
- Process structuredness
- Customer focus
- Potential for IT enablement

When the degree (high or low) of each of these four characteristics has been determined, (Kettinger et al. provide a means to determine them) one can actually determine which activities need to be focused on. The following table 3.3 depicts this argument:

| | Focus | |
|---|---|---|
| **Project Characteristics** | **High** | **Low** |
| **project radicalness** | S1A1, S2A1, S4A1, S4A2, S4A3, S5A1 | S3A1, S3A2 |
| **process structuredness** | S4A1, S4A2, S4A2 | S3A1, S3A2 |
| **customer focus** | S2A4 | |
| **potential for IT enablement** | S4A4, S5A2 | |

**Table 3.3: Focus on BPR projects with respect to their characteristics (Kettinger et al. 1997)**

The codes in the cells of table 3.3 (like S1A1) refer to the activities described in the stage-activity framework of figure 3.9. Table 3.4 subsequently depicts the actual type of tools and techniques, which could be used when the project characteristics are known:

| Project characteristics | Applicability | Technique category |
|---|---|---|
| All projects … | … require …<br>… need … | project management<br>problem solving and diagnosis |
| The more customer focused … | … the more important is … | customer requirements analysis |
| The more structured the process … | … the more useful is …<br>… the more feasible is …<br>… the more applicable is … | process capture and modeling<br>process prototyping, simulation<br>process measurement |
| The more IT enables process change … | … the more relevant is … | IS systems analysis and design |
| The more radical the project … | … the greater the reliance on …<br>… the higher the demand for …<br>… the more essential the …<br>… the greater the criticality of … | business planning<br>creative thinking<br>organizational analysis & design<br>change management |

**Table 3.4: Use of BPR techniques in relation to project characteristics (Kettinger et al. 1997)**

We will use the same typology to determine the project characteristics of the two case studies carried out in the air cargo industry (chapter 4). Subsequently, we will be able to determine whether MND initially was a good method to use, i.e. to what extent we actually could expect MND to contribute to the project. Furthermore, we will come up with a typology of projects for which MND could especially be useful.

## *3.5 Validation model*

### 3.5.1 Definition of the model

The previous section of this chapter described three different research areas from which we were able to further position and characterize MND and to derive a number of criteria to evaluate the contribution of MND within a certain redesign project. In this section, the final validation model will be presented, which incorporates these three perspectives. This model will be the conclusion of the deduction phase that we started at the beginning of this chapter.

The work of Bosman (1986) told us that MND possesses two different perspectives. A conceptual prescriptive and an empirical descriptive one. Both perspectives need to be validated individually.

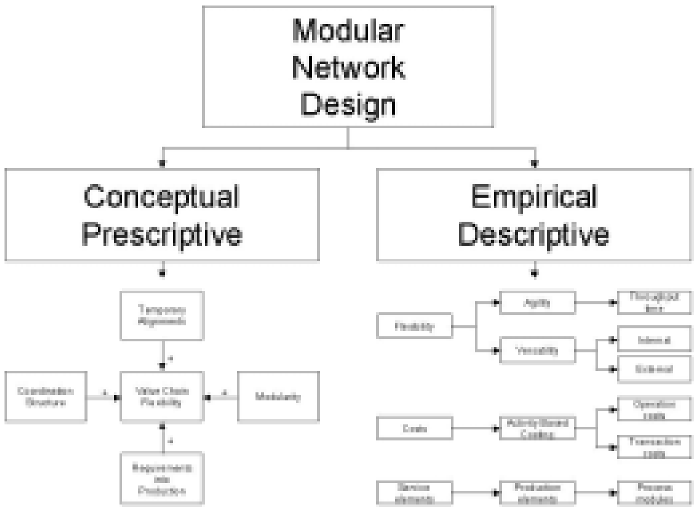


**Figure 3.10: The two perspectives of MND**

Furthermore, Bosman argued that the conceptual prescriptive part needs to be translatable into an empirical model and the empirical descriptive part needs to possess a conceptual part. These are the arrows in the Bosman framework of figure 3.4. This means that we need to analyze two things:

1. Assess the possibility of translating the constructs of the conceptual prescriptive MND, such as the temporary supply chain coordinator and the use of modularity, into empirically useful guidelines or methods.
2. Determine whether the assessment and visualization techniques of the empirical descriptive MND are the right methods to analyze, e.g., EDI investments or supply chain flexibility and whether the concepts flexibility and costs have been adequately operationalized within the empirical model.

With respect to the first topic the following can be said. The five constructs were defined by Hoogeweegen; we will investigate whether these constructs could indeed be practically useful and lead to specific guidelines. The more specific these guidelines can be formulated and the more applicable they are, the more valid the conceptual prescriptive model will be in practice. We will need to find empirical evidence within the case studies to verify whether this is indeed the case. If not, we need to be able to explain the lack of usefulness. The next section elaborates in more detail on the validation method.

We already elaborated on the second topic by discussing DSS validation literature (3.4.2) and research on BPR methods, tools and techniques (3.4.3). Different types of validity were mentioned, such as logical and data validity, all further specified in several subtypes. To validate the empirical descriptive part of MND, for each of these types it needs to be determined – within the empirical cases – to what extent they are achieved. The precise way this process is carried out will, again, be described in the next section - 3.5.2.

### 3.5.2 Validation method: filling in the framework

As mentioned in section 2.4.3, we will validate MND within one specific empirical setting: the air cargo industry. In the subsequent section – 2.4.4 – we described our research protocol, i.e. the plan of approach behind an application of MND. After previous discussion on the development of our validation model, it is clear that this research protocol needs further elaboration to determine the steps in the validation process more precisely. This is the subject of this section.

Assessing validity in general is a difficult task. Whenever one uses a theoretical model to describe, analyze or predict an empirical situation one needs to be sure that the elements of the model and their mutual relationships are sound, i.e. based upon some well-established theory or perception. Often, one refers to earlier research on the same topic to demonstrate that the elements used are indeed valid. Further, one can collect empirical evidence to confirm the theoretical model. Using, e.g., statistical techniques or a qualitative approach, one can subsequently establish the legitimacy of the model. Often, a validation effort is a combination of both approaches, as we will do as well. The research literature on MND-related topics has already been discussed quite extensively in the previous sections. In the process of our case studies, we will refer to these articles when required to analyze the validity of specific (theoretical) statements.

Especially the validation of the conceptual prescriptive part of MND will be based on a comparison between the current views in the literature and the way these views have been included in MND. The assessment of the possibility of translating the constructs of the conceptual prescriptive MND into empirically useful guidelines or methods will be done as follows. Within each case, we will first determine whether the constructs are already applied and operationalized by the stakeholders. Second, we will analyze - in a qualitative manner - why these constructs in the network or industry under study are applied, or not. To be able to do this, we need to define the opposite for each variable at hand. In this manner, we can actually come up with some - binary - measurement of each variable.

This leads to the following variable definitions:

| Variable | Opposite |
|---|---|
| Temporary alignments | Permanent, fixed alignments |
| Central coordinator/coordination | No central coordinator and/or decentral coordination (multiple coordinators) |
| Direct translation of requirements into production | Separation between requirements and production |
| Modular design | Integral design |
| Value chain flexibility | No value chain flexibility (e.g., rigidity, tardiness |

**Table 3.5: Variables of the conceptual prescriptive MND and their opposites**

In other words within the case studies we need to determine whether the original variable is present (i.e. applied and used) or its counterpart. Furthermore, we will need to determine whether there are any mutual correlations or causalities between these variables.

Research data to validate this MND perspective will be collected in three ways:
1. By conducting semi-structured interviews with managers involved in the case studies
2. By studying case-specific literature, i.e. literature on transport and logistics
3. By evaluating the researcher's own experiences during the execution of the empirical study

The third way is the most subjective of the three and thus requires the most caution and carefulness in drawing any conclusions. However, in action research the researcher is actually intervening in the process at hand and therefore, we can learn from these experiences as well. As often in qualitative research approaches, the strength of the approach lies in the derivation, presentation and interpretation of the conclusions based on collected evidence.

With respect to the validation of the empirical descriptive part of MND we make use of the framework of Finlay & Wilson (1997), thus it is seems obvious to use their validation methodology as well. Unfortunately, they do not present a worked out methodology to determine the value of each of the validity types of their model. They only state: 'A *validity framework* needs first to be developed, to be followed by the development of a *validation methodology* contingent upon the exigencies of the situation in which the DSS is designed, implemented and used. The validity framework provides the end that the validation methodology seeks to attain. This paper addresses the first requirement.' (Finlay & Wilson 1997:171). The consequence of this is that our validation effort cannot be based on an already-used and proven method. We will need to develop a methodology of our own.

We already presented the BPR framework of Kettinger et al. (1997) in section 3.4.3. This framework will serve as our method to determine the general validity of the model, in particular its robustness and conceptual and operational validity. The Kettinger framework is useful in classifying the redesign project at hand and determining the appropriateness of using MND in these circumstances.

For the other validity types, of which logical and data validity are most important, we partly rely upon literature, which explicitly deals with the elements of our study. This means literature on Activity Based Costing and Supply Chain Costing, agility, versatility, PERT and the Critical Path Method and literature on the customization of goods and services needed to analyze to what extent the direct translation of customer requirements into production is feasible and operationalized correctly.

Another important source of information is the development of *Erasmus in Chains* (EiC): an automated software version of MND. This program – which may be considered a DSS - was designed to support the modeler and/or decision-maker in the consecutive steps of the MND plan of approach (see figure 3.2). Next to the execution of the two empirical cases, the translation of MND into a computer program which automated the MND modeling steps, taught us a great deal about the validity of the empirical descriptive model. We needed to come up with concrete methods and algorithms to implement all assessment elements of MND in the software program. This process forced us to go deeper into the specifications given by Hoogeweegen and test their validity by means of the development of the program. In design-oriented research, this type of validation is common practice. The process of starting from a number of (theoretical) design specifications and arriving at a working system or tool is considered an important part of the validation of the model in itself. An example of such an approach can be found in Pine (1989), where the design, test and validation of the Application System / 400 (AS/400) is described. In addition, Lenard et al. (1998) consider the development of the prototype and the initial consultation with the first expert as an important phase of the validation process.

Obviously, the experiences of the two empirical cases add to our knowledge about the validity of the empirical descriptive part of MND. Especially, data validity can only be determined based on an application of the model.

Finally, table 3.6 below describes the entire MND validation framework. Whenever one of the validity variables is investigated in a certain source, it is indicated with a √. This means that either during the development of *Erasmus in Chains* or within one or both of the empirical studies this type will be discussed and analyzed. One can see that the Distribution case focuses on the Empirical Descriptive MND, while the Air Logistics case mainly deals with the Conceptual Prescriptive part. At the end of the next chapter, we will try to replace the √'s by actual conclusions about the 'value' of each variable. These 'values' will refer to whether a certain variable is indeed valid or not and subsequently how the validity of the variable may be improved. Based on our analysis we will 'score' each validity variable as either Low, Sufficient or High. The value depends on a number of criteria, which have already been specified in the previous sections for each individual variable. In general, the theoretical foundation in literature, the operationalization and the added value in practice are strong determinants for each validity type.

| | Validity variables to be investigated | | Method | Source: EiC Development | Source: Distribution case | Source: Air Logistics case |
|---|---|---|---|---|---|---|
| **MND Conceptual Prescriptive** | **Independent variables** | Temporary Alignments | Interviews, Literature, Own experience | | | √ |
| | | Coordination Structure | | | | √ |
| | | Requirements into Production | | | | √ |
| | | Modularity | | | | √ |
| | **Dependent variable** | Cost efficient customized supply chains | | | | √ |
| **MND Empirical Descriptive: Flexibility, costs and visualization** | **Logical validity** | Analytical validity | Literature, Empirical verification | √ | √ | |
| | | Theoretical validity | | √ | √ | |
| | **Data validity** | Accuracy | Empirical verification | | √ | |
| | | Precision | | | √ | |
| | | Theoretical validity | | √ | √ | |
| | **General validity** | Conceptual validity | BPR Framework of Kettinger et al. (1997) | | √ | √ |
| | | Robustness | | | √ | √ |
| | | Internal validity | | | √ | √ |
| | | Operational validity | | | √ | √ |
| | | Experimental validity | | | √ | √ |
| | **Perceived I'face val.** | Theoretical validity | Own experience, Human-Interface interaction literature | √ | √ | |
| | | Usability | | √ | √ | |
| | | Information validity | | √ | √ | |
| | | Face validity | Interviews | | √ | √ |

**Table 3.6: MND Validation Framework**

# CHAPTER 4 APPLYING MODULAR NETWORK DESIGN IN THE AIR CARGO INDUSTRY

## *4.1 Introduction*

This chapter describes the research efforts concerning the validity of MND. It is phase four of the empirical cycle of conducting research (de Groot 1969). Testing the hypothesis and thus filling out the validation framework of section 3.5 was done based on three sources:

1. The development of an MND-based Decision Support System, called *Erasmus in Chains*
2. Two action research studies, carried out in the air cargo industry.
3. Scientific literature

On the basis of the case protocol presented in section 2.4.4 and the validation framework of section 3.5, both empirical case studies are described and conclusions are drawn concerning the validity of MND and how it may be improved or enhanced on the basis of these conclusions.

The chapter commences with a brief description of the air cargo community and the various trends and developments going on in this sector. Section 4.3 then describes the background and process of developing *Erasmus in Chains*. The program was built to facilitate the different cost and throughput time calculations and to automatically produce the process visualizations (the process module networks) of MND. This is the first source for determining the validity of MND. Developing this system, i.e. trying to translate the MND model into a software program taught us a lot about the validity of MND, especially its logic and data model. Furthermore, during the development of this system, an attempt was made to extend the level of analysis of MND from single order to multiple order. The reason to do this and the consequences of this extension are explained in the same section (4.3).

*Erasmus in Chains* was used during the two cases, which were carried out at the freight division of a cargo carrier (from now on simply called *Carrier*, for reasons of confidentiality), within two different business units. Section 4.4 describes the first of these studies. This case was carried out to analyze five different freight orders that were placed at the business unit Distribution of the Engineering and Maintenance department. This business unit distributes aircraft spare-parts for the airline and its partners and customers, including newly purchased and repair goods worldwide. The reason for *Carrier* to execute the case was their desire to have a number of process handling scenarios to improve their chain performance formulated and analyzed by MND. From a research point of view, we were able to validate MND in an empirical setting. The focus of this case will therefore not particularly lie on the detailed business process data, but on the issues of concern for our validation model. This case will from now on be called the Distribution case.

The second case study also concerned the analysis of multiple orders, only this time all orders were placed by the same shipper over a longer period. This case dealt with the question whether and how a *Carrier* business unit, Air Logistics, could offer a fully customized door-to-door logistic concept to their customers. To answer these questions an analysis was made with MND of the transport chain of one particular shipper, ZXV[7] a large Scandinavian manufacturer. The first objective of the case study was to analyze the current situation of freight handling, where *Carrier* only took care of the airport-to-airport part. The second was to define and assess a number of alternative handling scenarios, where *Carrier* would take care of the entire door-to-door trajectory of this customer. This analysis might then be used to convince ZXV of *Carrier*'s ability to coordinate ZXV's door-to-door transport chain. This case study, denoted as the Air Logistics case, is discussed in section 4.5.

The chapter is concluded with an evaluation of the validity of MND to support the design of cost-efficient customized business networks. We discuss the applicability of the approach, its merits, but also some drawbacks are mentioned. This leads to a number of suggestions and guidelines about how the model could be improved together with directions for further research on MND and related topics. Finally, arguments are given why the next research module focuses on business modularity and mass-customization and how the process modeling approach MND could profit from this research.

## *4.2 Developments in the air cargo community*

Air cargo providers play a crucial role in helping shippers improve their supply chain operations, particularly in the international arena. The supply chains of these shippers have to live up the customer's requirements that the movement of their products is executed quickly, inexpensively and with zero defects. Late deliveries or incomplete paperwork are unacceptable. The increased demands on the supply chain and the movement to source internationally accentuate the need for fast and reliable transportation services. Especially with the build-to-order mass-customization strategies, as discussed in the previous chapters, efficient flawless transportation is essential and because air transportation is the fastest transport mode, it is often used to compress the lead-time of delivery.

According to Hebert et al. (1998) there is increasing value placed by shippers on full-service, integrated management of door-to-door air cargo service, including the physical product and information flows. Shippers are looking for a single-stop service provider who picks up, transports and delivers across multiple modes and carriers. Nowadays several parties compete in becoming such single-stop providers. They can be divided in four basic categories: (1) Freight Forwarders, (2) Integrators, (3) Freight Airlines and (4) Passenger Airlines. Traditionally each of these parties offered different services and benefits to shippers merely related to specific density, volume or weight categories. Nowadays, these segments are increasingly overlapping and competing with each other for high value and high margin cargo, putting increased pressure on tariffs. Especially the integrators are getting the heavier and more profitable cargo loads. FedEx, a large integrator, for instance, already has the biggest air cargo fleet in the world. *Carrier* is constantly investigating its own role in this dynamic environment and (re-) evaluating its strategies. For this reason, *Carrier* saw fruitful opportunities in the use of MND for analyzing their processes and performance, as well as their possible role within the air cargo community.

[7] For reasons of confidentiality the name of the company is fictitious

## *4.3 Enhancements of the original MND: Erasmus in Chains*

In line with Hoogeweegen's remark about the limited ability of MND to only assess one order at a time it was decided, before validating it in an empirical setting, to try to extend the level of analysis from single order to multiple order level. The main reason behind this effort was to make the model more realistic and therefore its results more useful for decision support with respect to the (re-) design of value chains. The simultaneous analysis of multiple orders should take account of order interdependencies. The other functionalities and features of MND were left unchanged.

As mentioned above, a decision support system, called *Erasmus in Chains*, was built in which the multiple order version of MND was implemented. The system should support the modeler and/or decision-maker in the consecutive steps of the plan of approach of figure 3.2. After entering all available service elements, production elements, process modules and resources in the system, just as their mutual relations, modeling the orders should be straightforward and easy. By selecting the desired service elements and subsequently choosing the accompanying production elements and the sub-contractors, the construction of the process module network should automatically be carried out by the system itself. EiC also had to support the comparison of different scenarios with the current situation of order processing.

*Carrier* itself considered this a useful extension of the single order version of MND as developed by Hoogeweegen and applied in the air cargo industry. This addition could in their opinion improve both the face and the general validity of the method (source: interviews with *Carrier* managers).

Translating MND into a computer program and extending the model to multiple order level however brought up a number of complexities, which will be discussed in this section. This discussion will teach us more about the validity of MND, especially the validity of the logic and data model. Note that the actual applications of the system will be discussed later. This section only discusses the complexities and challenges, which arose during the development of the Decision Support System.

While incorporating the four steps of MND (order placement, chain formations, allocation and assessment, redesign), described in section 3.3, five main issues came up during the development of Erasmus in Chains. All of these issues had to do with the operationalization of the algorithms of the empirical descriptive MND and the underlying theoretical concepts of these algorithms (see section 3.4). First, issues related to the way in which order interaction should be operationalized in the system. Second, the design of the algorithm used for determining the total amount of process delay caused by a possible shortage or absence of required resources. Third, the analysis of costs based on the methods of Activity Based Costing. Fourth, the method to define the dependencies between the process modules and to calculate the number of possible sequences and the sequence in which they are executed, based on the actual selection of service and production elements. Fifth, the question how to operationalize the assessment of the degree of flexibility of a supply chain. As already mentioned, all of these issues arose independently of the actual applications of the system.

### 4.3.1 Order interaction

The first issue had to do with how order interaction had to be implemented and designed in Erasmus in Chains. The idea behind the development of a multiple order version of MND was the desire to increase the realism of the model and therefore the reliability of its results. We would thus be able to better analyze the limitations and possibilities of mass-customization strategies (although practically we might be confronted with the impossibility to collect data for all other orders being processed in a chain at a certain moment or period of time). However, MND was initially developed for single order analysis only. Moreover, the whole idea of MND was based on the notion that *single* customers formed the basis of engineering value chains and the fulfillment of their *individual* requirements should be the core objective of organizations. This view was already illustrated in figure 3.2 in chapter 3. This idea was left unchanged in the multiple order version of MND. Each individual order still formed the basis of the engineering of the value chain.

Mainly for this reason, the original single order perspective of MND, it was not possible to include a real multiple order perspective, which would, e.g., enable the analysis of consolidation of orders, which could lead to economies of scale or scope. In other words the possible advantages of 'batching' individually customized orders (the 'mass'-aspect of mass-customization, see Pine 1993) could not be investigated. The only real change that was made to MND was the possibility to analyze the interaction of different individual orders with each other. These interactions implied that each order was analyzed individually, subject to the other orders being processed in the system at the same moment. The occurrence of possible delays caused by insufficient resources, needed to execute a particular order, could be investigated in this manner. The difference between the MND multiple order perspective and 'real' mass-customization is illustrated in figure 4.1 below.

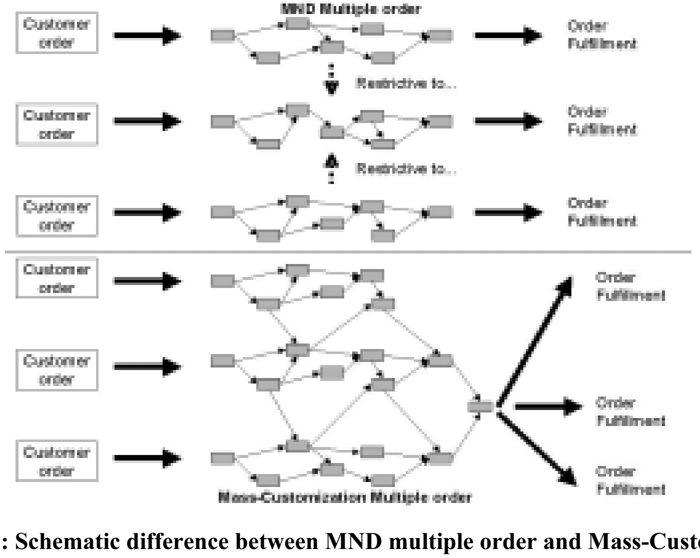


**Figure 4.1: Schematic difference between MND multiple order and Mass-Customization**

With respect to the logic model of MND (and its validity), this implies the following. While the logic model of MND is still only suitable for the analysis of single orders, subject to other orders being processed concurrently, the model cannot be considered theoretically valid for investigating *mass*-customization strategies. To investigate the 'pros and cons' of mass-customizing customer orders one really should be able to at least investigate the implications of combining different orders in an effort to achieve either economies of scale or economies of scope or preferably both. Firms achieve economies of scale when their operating costs increase at a lower rate than their output. Economies of scope arise when the joint costs of producing multiple products or outputs is less than the costs of producing each product or output by itself (Panzar & Willig 1981, Lei et al. 1996). Customizing products and services should lead to economies of scope, rather than economies of scale - ideally serving ever-smaller niche markets without the high cost traditionally associated with customization. Or as Pine states it: '… profit from economies of scale from mass production and at the same time enjoy economies of scope by creating high-value products custom-tailored for buyers'. We may thus conclude that an analysis with multiple-order MND does not shed more light on these issues.

### 4.3.2 Algorithm for calculating process delays caused by limited resources

An issue closely related to the previous one is the design of the limited resources algorithm. The purpose of the algorithm was to calculate the delays that would occur for each individual order due to the absence or shortage of resources, needed to execute certain process modules. In other words an algorithm needed to be developed that effectuated the situation depicted in the bottom half of figure 4.1, where the execution of other orders at the same time could limit the execution of the particular focal order being analyzed.

The final algorithm looked as follows:

**Start.** Initialization: The initial process module network, including the start and finish times of all process modules, is the one calculated with the depth-first search algorithm, for example, described in Cormen (1990). It uses the indicated process module dependencies, which will be further discussed in section 4.3.4.

**Step 1.** Set t=0. This is the time the first order under analysis is supposed to begin.

**Step 2.** Check if all N orders are already fulfilled, i.e. if remaining duration of all process modules is zero. Yes: goto End. No: goto step 3.

**Step 3.** Determine number of orders (n) that should start at time t. Repeat step 4 through 10 n times (i=1 to n).

**Step 4.** t'=t

**Step 5.** Check if remaining duration of process module (i) at time t' = 0. Yes: goto step 10. No: goto step 6.

**Step 6.** Check if all required resources are available to execute process module (i) at time t'. Yes: goto step 9. No: goto step 7.

**Step 7.** Delay process module (i) = Delay process module (i) + 1, goto step 9.

**Step 8.** Duration process module (i) = Duration process module (i) – 1

**Step 9.** t' = t' +1, goto step 4.

**Step 10.** Update process module network: Defer all non-executed process modules which have process module (i) as (in)direct predecessor with 'Delay process module (i)' minutes, i=i+1, goto step 4.

**Step 11.** t = t +1, goto step 3.

**End.**

The algorithm is closely related to standard algorithms provided within, for instance, Microsoft Project, called 'Resource Leveling' to resolve resource conflicts or overallocations by delaying or splitting certain tasks. When a resource is leveled, the resource's selected assignments are distributed and rescheduled according to the resource's working capacity, assignment units, and calendar, as well as the task's duration and constraints. The outcome of this algorithm is an indication of the delays occurring because of a shortage in recourses required to execute certain process modules. The following two figures illustrate this. Figure 4.2 depicts the initial process module network when all resources are available all the time with unlimited capacity. At the bottom of this figure, resources 1 and 2 are added with their availability. Resource 1 is available from t=0 to t=2 and unavailable from t=2 to t=3. This 2:1 rhythm continues infinitely. Resource 2 has the same structure only it is shifted one period. Both resources have a capacity of one.

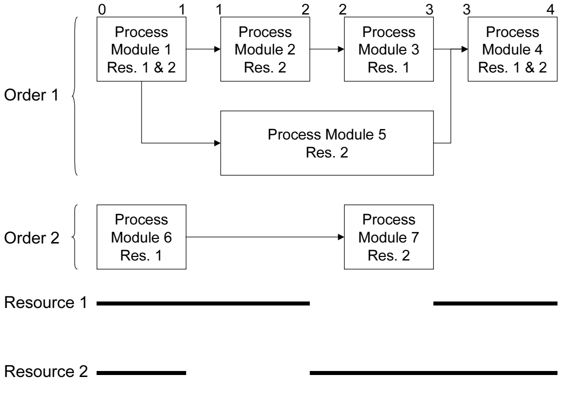


**Figure 4.2: Initial process module network with unlimited resources**

When the algorithm is used to calculate the new process module network restricted by the resource availability, the outcome would be as follows:

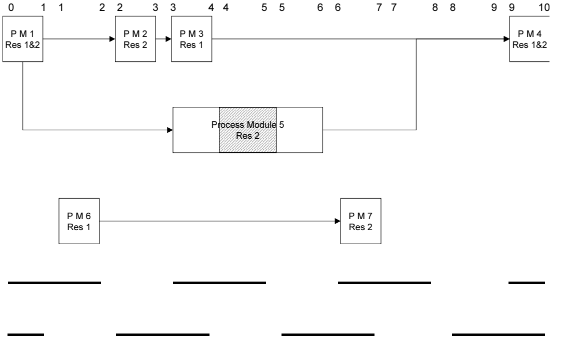


**Figure 4.3: Recalculated process module network with limited resources**

The algorithm was extensively verified by its programmer for many different instances. Nevertheless, one remark can be made about the algorithm and its functionality. It concerns the inability of the algorithm to distinguish between different types of resources. On the one hand there are resources that diminish and need to be replenished after usage (such as pieces of paper) and on the other there are resources that are temporarily unavailable, but that can still be used afterwards (such as trucks or labor). The algorithm fails to distinguish between these types; it assumes all resources are of the latter type and thus never need to be replenished. This causes the algorithm to be less reliable than an uninformed user would expect.

### 4.3.3 Cost analysis

In section 3.3.2, it was mentioned that the cost analysis of MND makes use of Activity Based Costing (ABC). The desire for operational information about activities led to the development of this method (Turney 1991). The power of ABC is the clearly portray of cost and non-financial information. The ABC model is based on the combination of a cost assignment and a process view visualized in figure 4.4.

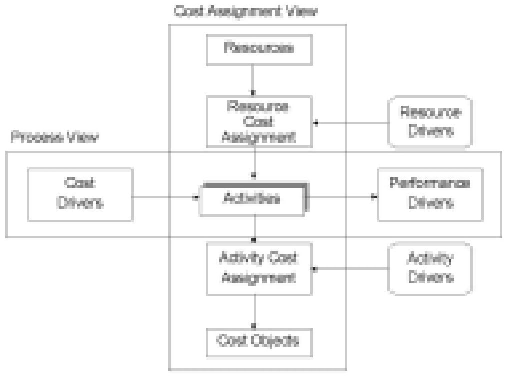


**Figure 4.4: ABC Building Blocks (Turney 1991)**

In the cost assignment view, the specific order is the cost object. The cost object requires activities and these activities require resources. The flow of costs is in the other direction, from the resources to the cost object. The process view provides information about the work done in an activity and the relationship of this work to other activities. Turney (1991) defines a process as a series of activities that are linked to perform a specific goal. Each activity is a customer of another activity and, in turn, has its own customers. Activities are all part of the customer chain, working together to provide value to the outside customer. ABC assigns overheads (indirect costs) based on the activities that cause those costs to occur (cost drivers). By focusing on activities, which consume resources, ABC can reveal more useful information for product or service costing (Adams 1996). Originally, ABC was developed for the manufacturing environment. Increasingly however, ABC is used in a distribution environment. Van Damme & Van der Zon (1997) translated the original ABC to such a distribution environment. While our applications of MND also take place in such an environment Van Damme's view is used here to explain the ABC method a little further.

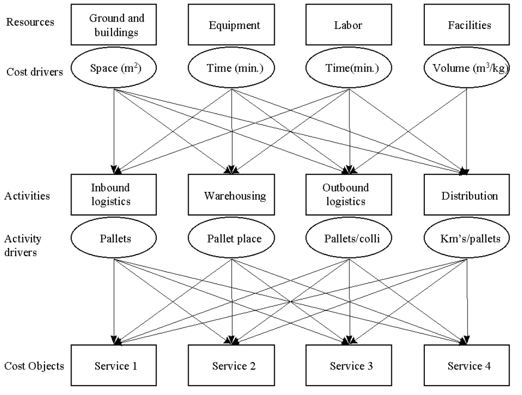


**Figure 4.5: ABC in a distribution environment (Van Damme & Van der Zon 1997)**

In figure 4.5, it can be seen that ABC makes use of a number of different building blocks. The first layer is resources, the means required to perform an activity. Second, cost drivers, the unit of measurement for these resources. Third, activities, the tasks to be performed. Fourth, activity drivers, a factor used to assign costs from an activity to a cost object. Fifth, cost objects to which the costs are assigned. When comparing this framework to the logic model of MND (section 3.4.2) we notice that MND only uses four building blocks: the activity drivers are not included. MND only consists of the building blocks resources, cost drivers, activities and cost objects. The omission of activity drivers could lead to problems inadequately representing the costs of a customer order when an order consists of different activity drivers.

This finding is closely related to the problem of order interaction (see section 4.3.1). It was concluded there that the multiple order version of MND is unable to analyze the consolidation or 'batching' of orders. Because of the absence of activity drivers in the logic model of MND, it is formally not possible either to analyze a single order when this order consists of more than one activity driver. This means, for instance, that it is difficult to analyze a single order that is split or consolidated during the fulfillment process, something that frequently happens in the transport sector. This implies that the cost-section of the logic model of MND needs further improvement.

### 4.3.4 Construction of the process module networks

An important problem occurred with respect to the sequencing of process modules in process module networks. The theoretical justification for using modules is again, related to the concept of mass-customization. The idea is that by modularizing products and processes one can achieve high flexibility and customization by constantly changing the way modules interact and by selecting only those modules, which are required by the end-customers. This should lead to a myriad of different products and services and the way they are produced. MND builds forth on this notion by introducing service elements, production elements and process modules. Customers specify their requirements by selecting service elements from the available set, after which they are materialized in production elements, which subsequently consist of a number of modular activities. The latter together constitute the process module network, which depicts the precise way the order is fulfilled.

Obviously, *Erasmus in Chains* also needed to reflect this flexibility. An algorithm was needed that would determine what each process module network would look like, depending on the actual selection of service elements, production elements and sub-contractors. This algorithm should furthermore be able to handle multiple orders simultaneously. One can see however in section 3.3.3 that no such algorithm was formally formulated by Hoogeweegen in his thesis, even for the single order version of MND. Hoogeweegen only briefly describes (by use of an example) in his thesis how he dealt with this problem in his case study (Hoogeweegen 1997:67-68), which will be summarized below.

Each service element is linked to a number of different production elements. Each production element is linked to (i.e., offered by) only one organization. Furthermore, each production element is linked to (i.e. consists of) a number of different process modules. The actual order sequence is only determined at the level of the process module. For each process module its (possible) successors are indicated. An example of the link between production elements, process modules and their mutual sequence is given below.

| **Production element no.** | **Process module no.** | **Process module name** | **Successor (process module no.)** |
|---|---|---|---|
| **A4** | .. | .. | 04 |
| | 04 | Make customs document | |
| **A5** | 04 | | 05 |
| | 05 | Make driver instruction | 06 |
| | 06 | Give driver instruction to driver | 07 |
| | 07 | Drive to shipper | |
| **A6** | 04 | | 08 |
| | 08 | Make road transport order | 09 |
| | 09 | Send road transport order | |

**Table 4.1: Example of linking production elements with process modules (Hoogeweegen 1997: 68)**

Each selected production element invokes one or more process modules and a number of relationships among these modules. Selecting production elements A4, A5 and A6 in this example would therefore lead to the following process module network:

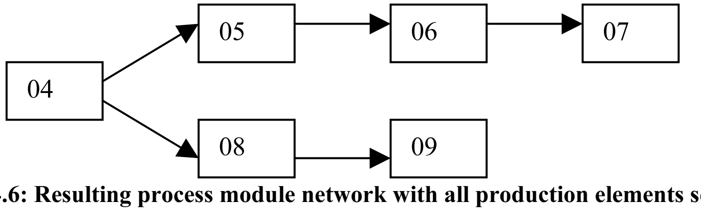


**Figure 4.6: Resulting process module network with all production elements selected**

However, if for some reason production element A5 would not be selected, the process modules 05, 06 and 07 would be left out of the process module network. Vice versa, the exclusion of A6 would lead to a network without the process modules 08 and 09. This is everything Hoogeweegen describes about the sequencing of modules and how to establish the links between the MND elements. He does not describe how to deal with other, more complicated instances. In fact, what is needed is an architecture for linking the different process modules with each other and with the service and production elements. Or as Pine et al. (1993) call it: 'The key to success is designing a linkage system that can bring together whatever modules are necessary – instantly, costlessly, seamlessly and frictionlessly' (Pine et al. 1993:110) and '…managers need to create an architecture for linking the process modules that will permit them to integrate rapidly in the best combination or sequence required to tailor products or services' (page 115).

A major challenge therefore, was how to implement Hoogeweegen's brief description into Erasmus in Chains, while keeping account of the multiple order extension and furthermore to leave the possibility open to define alternative scenarios. The brief example of Hoogeweegen was used as guideline for the algorithm of *Erasmus in Chains* and the way the MND elements had to be entered in the system. This led to a number of complications when EiC was used for modeling and analyzing value chains, which will be described in more detail when the findings of the first case study are discussed.

### 4.3.5 Assessing flexibility

An important aspect of MND is its supposed ability to determine the flexibility of a value chain. Hoogeweegen divides flexibility in two components: agility and versatility as can be seen in the logic model of MND described in section 3.4.2. This logic model needed to be operationalized in *Erasmus in Chains*. Hoogeweegen translated agility into order throughput time and this was done in *Erasmus in Chains* as well. However, agility comprises far more than simply order throughput time. This immediately follows from the original definition of Nagel & Dove (1991): 'The ability to thrive and prosper in a competitive environment of continuous and unanticipated change and to respond quickly to rapidly changing markets driven by customer based valuing of products'. Bahrami (1992:35) uses a similar definition: '… the ability to move rapidly, change course to take advantage of an opportunity or to side-step a threat'. Such definitions are very difficult to operationalize in a DSS such as Erasmus in Chains, while they are both merely formulated on a strategic level, where a more specific, operational level is required. Hoogeweegen partly excuses for this drawback by stating that he mainly focused on the operational aspects of agility and versatility, in the context of strategic flexibility. Unfortunately, further elaboration on this is not given.

Furthermore, versatility is divided into internal versatility and external versatility, where both should be as high as possible to customize business processes, according to Hoogeweegen. Anderson & Pine (1997) disagree with this claim by stating that external versatility should be as high as possible, while internal versatility should be minimized. External versatility is defined as the number of possible different combinations of service elements and internal versatility is the number of different ways a selection of service elements can be translated into production elements. However, Hoogeweegen does not really present a measure to determine the degree of internal or external versatility of a supply chain. Determination of the number of different combinations of service elements would at least require a feasibility check of each combination of elements. This would be very application-specific. Measuring internal versatility brings up another issue which has to do with linking service elements to production elements. In section 4.4.3, we will further elaborate on this problem. Obviously, these findings largely complicated the operationalization of versatility in *Erasmus in Chains* and this eventually even led to a complete elimination of the concept of versatility from the system.

Because a good operational definition of versatility is lacking and agility is operationalized in a very limited and deficient manner, we may assert that Hoogeweegen's conclusion that EDI could indeed increase flexibility (Hoogeweegen 1997:145) might be somewhat too ambitious. Although he states that the particular levels of agility and versatility should be treated in relative terms, not in absolute ones (Hoogeweegen 1997:27-28), the conclusion remains hard to sustain.

### 4.3.6 Summary

To summarize the previous sections it can be said that only the following small adjustments were made to the original logic and data model of MND (see section 3.4.2).

Logic model

- Algorithm for calculating process delays caused by limited resources

Data model

- Resource capacities

The following adjustments could however not be made:

Logic model

- Analysis of consolidation or 'batching' of orders.
- Formal algorithm or architecture to determine the final construction of the process module network based on the specific selection of service and production elements.
- Decision rules for selecting alternative order fulfillment procedures, e.g., to avoid delays (not required beforehand).
- Operationalization of internal and external versatility (even resulting in a complete elimination of both constructs from the system).

Data model

- Activity drivers.

To conclude this section we may therefore already state that the theoretical validity of both the logic and the data model of MND, even before the applications are carried out, is not sufficient. The fit between the ambitions of MND (analyzing cost efficient value chain flexibility) and its actual operationalization in a DSS can already be called inadequate. Nevertheless, not any model can be flawless and complete, because it can by definition only depict part of the reality. Furthermore, programming a model into a DSS could also cause difficulties, which further hamper the validity of the model as a computer program. MND could, with all its shortcomings, still be a useful and valid method for specific instances. These instances will however be limited to:

- analysis of a single order at a time, subject to the availability of limited resources for execution
- analysis of lead-time (or throughput time) only; no versatility or flexibility assessment possible due to inadequate operationalization
- cost analysis of single order for one activity driver only; most likely, costs are inadequately represented when an order consists of different activity drivers

With this in mind, we will now continue with the two cases applied in the air cargo industry aiming at further validation of the MND model.

## *4.4 First case: Distribution*

### 4.4.1 Introduction and objectives

At the time of the case study, Distribution was a business unit of the Engineering and Maintenance department of *Carrier*. This business unit distributes aircraft spare-parts for the airline and its partners and customers, including newly purchased and repair goods worldwide.

Normally, shippers rarely deal directly with a scheduled airline such as *Carrier*. They rely on freight forwarders to act as intermediaries. Most freight forwarders specialize in either ocean freight or airfreight, although some handle both (e.g., Expediters International). Freight forwarders all do the same thing: they set up international transportation for a shipper's cargo. Many forwarders also handle inland pickups and deliveries, freight consolidation, shipping documentation, customs clearance, cargo insurance, warehousing, distribution, electronic cargo tracking, and value-added logistics. Most forwarders are expanding into different modes and different geographical areas. For regular goods an (air) transport trajectory, from consignor to consignee, therefore looks as follows.

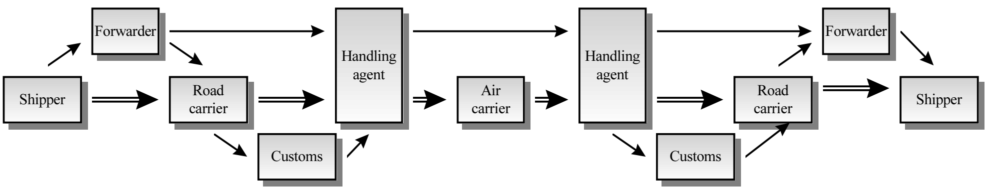


**Figure 4.7: Regular cargo transport trajectory**

However, because Distribution operates in a special segment of the air cargo industry, i.e. distribution of spare parts and repair goods, they are able to surpass forwarders for most of their shipments. They take over the role of the forwarder for these types of goods by designing their own shipping networks by arranging customs handling, warehousing, tracking and tracing etc. for their customers. To put it in MND terms: Distribution acts as chain coordinator for these types of goods. Moreover, most of the other parties involved in their transport network are close partners or subsidiaries of *Carrier*. This occurrence enabled us to describe the processes in detail (i.e. on process module level), while we were not restrained by any political or competitive barriers. We were thus able to access and collect a significant amount of data required for the analysis with MND. On the other hand, the presence of non-*Carrier* partners and *Carrier*'s desire to become coordinator of the chain was the subject of study in the second case study at Air Logistics.

Distribution initiated the development of *Erasmus in Chains* (started in Winter 1996) based on their impression of the previous work of Hoogeweegen in the air cargo sector. They thought a similar analysis, with a few enhancements could improve their own performance and increase their insight in their own processes and those of their partners. Eventually they intended to use the newly developed system *Erasmus in Chains* for their regular order planning, analysis and network design. As a test case the system was applied on five recently placed, representative orders handled by their business unit.

### 4.4.2 Brief order description

As mentioned above, five different orders were analyzed. These orders differed on a number of aspects. The first aspect concerns the type of road transport offered by *Carrier* Physical Supply. Physical Supply, a division of Distribution takes care of the road transport within and outside the Schiphol area. The service offered by Physical Supply falls into four categories: regular, courier, aviation distribution and special transport. Whether orders are considered regular, courier or aviation distribution orders depends on the size of the package and the maximum delivery time. In the case of regular transport, it concerns regular goods, which must be delivered within 4 hours after enrolment within the Schiphol area. Courier service deals with relatively small goods, with a maximum delivery time of one hour, again within the Schiphol area. Aviation Distribution concerns a so-called dedicated throughput time transport service within the Netherlands. Special transport finally concerns the delivery of large goods and packages. The orders selected concerned regular, courier and aviation distribution orders.

The second aspect concerns the type of customer requesting transport. Distribution normally offers its service to three types of customers: *Carrier* Technical Service (abbreviated as TD; includes several business units and contracted parties), *Carrier* in general and external parties. In figure 4.8 below, the relation between the customer types and the service of Physical Supplies is depicted. For the orders under analysis four orders were placed by *Carrier* Technical Service or one of their contractors, none by *Carrier* in general and one by external customers.

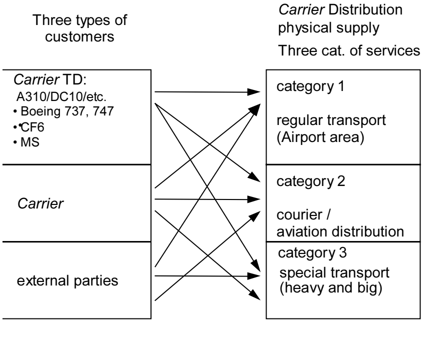


**Figure 4.8: Distribution's Customers and Physical Supply service types**

A third aspect is the question whether the orders concerned an Aircraft on Ground (AoG) situation. AoG orders usually have higher priority than routine orders, because the aircraft in which the goods need to be loaded is almost ready and waiting for departure. Two orders concerned an AoG situation. As mentioned above, for all selected orders Distribution functioned as the chain coordinator. The first order selected concerned an order from one of TD's regular customers, BU CF6. Order numbers 1a and 1b are each other's counterpart. The former is an export order from Amsterdam Airport (SPL) to

Cincinnati (USA) and the latter is its import equivalent, which takes place after the goods have been repaired. The same principle applies to orders number 2a and 2b; a shipment from a particular shipper to New York and back. Orders number 3a and 3b are just about the same, rather order 3b concerns an Aircraft on Ground (AoG) situation, where 3a is a regular situation. Order 4 is also an AoG order only this time it concerns a local Schiphol order. Finally, the fifth order is a shipment within the European Union, from Schiphol to Toulouse. For orders 4 and 5, no flight was involved; only trucks were used. The selected orders gave a good overview of ordinary practice of the BU Distribution according to themselves. Table 4.2 shows all orders analyzed[8].

| Order No. | Shipper | Point of departure | Consignee | Destination | PS Cat. |
|---|---|---|---|---|---|
| **1a** | Shipper 1 | A'dam Airport East | Consignee 1 | Cincinnati, USA | 1 |
| **1b** | Consignee 1 | Cincinnati, USA | Shipper 1 | A'dam Airport East | 1 |
| **2a** | Shipper 2 | A'dam Airport East | Consignee 2 | New York, USA | 1 |
| **2b** | Consignee 2 | New York, USA | Shipper 2 | A'dam Airport East | 1 |
| **3a** | Shipper 3 | Seattle, USA | BU 747 | A'dam Airport East | 1 |
| **3b** | Shipper 3 | Seattle, USA | BU 747 | A'dam Airport East | 2 (AoG) |
| **4** | Shipper 4 | A'dam Airport East | Consignee 4 | A'dam Airport C'ter | 2 (AoG) |
| **5** | Shipper 5 | A'dam Airport East | Consignee 5 | Toulouse, France | 2 |

**Table 4.2: Overview of orders analyzed**

### 4.4.3 Modeling the 'current situation'

This section describes the process of modeling these five orders with the use of MND: the first step of the analysis protocol of section 2.4.4. The 'current situation' stands for the way these orders were actually fulfilled by Distribution in the recent past. Data required to fill the MND data model was gathered for these particular orders. The data includes the activity durations, the resources used and their capacities and their costs. In addition, the participating organizations, the service elements, production elements and process modules had to be determined. The data was needed to fill the data model and to make the calculations with the MND logic model. For our purpose, i.e. validating MND, especially the process of data gathering and strengths and weaknesses of the approach are most important, together with a determination of the precision and accuracy of the data. Therefore, the detailed data that was collected will not be mentioned here[9]; only the issues of concern for our validation model (see section 3.5) are discussed.

**Definition of service elements**

Defining the total set of available service elements for Distribution proved to be the least difficult task. Distribution itself already made use of similar elements, mainly for marketing purposes. They used these elements to show their customers what kind of service they were able to deliver. They distinguished nine different categories, which we also used in our MND analysis (source: internal Distribution documents).

[8] Gathering specific information about sub-contractors in the US and other non-Dutch countries proved to be very difficult practically and financially. Therefore, this case was limited to Dutch-located organizations only.

[9] Detailed results can be found in the internal report 'Towards cost efficient supply chain flexibility - Case Study Report', August 1997 by M.R. Hoogeweegen, A.J. Klop, W.J.M. Teunissen, P.H.M. Vervest, G.J. te Winkel and M.J.J. Wolters.

Within each category, we defined specific service elements that would be useful for *Carrier*'s customers to select and thus customize their own shipping orders. We could however not validate whether the customers of Distribution actually did agree with the definition of these elements and whether they considered the definition to be adequate and sufficient. Our only source of approval was Distribution itself and they confirmed our defined elements.

The following table depicts the service elements defined for modeling the five orders:

| **category** | | **element** | | **category** | | **element** | |
|---|---|---|---|---|---|---|---|
| **ID** | **name** | **ID** | **name** | **ID** | **name** | **ID** | **name** |
| **S1** | Trans- | S1-01 | name shipper | | | S3-15 | Far East/Austral. to SPL |
| | action | S1-02 | order processing: paper | | | S3-16 | Mid Atlantic to SPL |
| | | S1-03 | payment in advance | | | S3-17 | South Atlantic to SPL |
| | | S1-04 | payment afterwards | | | S3-18 | Africa to SPL |
| | | S1-05 | electronic invoicing | **S4** | customs | S4-01 | import NL |
| | | S1-06 | paper invoicing | | clearance | S4-02 | export NL |
| | | S1-07 | tracking & tracing, paper | | | S4-03 | import USA |
| | | S1-08 | tracking & tracing, electr. | | | S4-04 | export USA |
| **S2** | shipment info | S2-01 | point of departure | | | S4-05 | import Singapore |
| | | S2-02 | destination | | | S4-06 | export Singapore |
| | | S2-03 | volume | **S5** | paper work | S5-01 | AWB, paper |
| | | S2-04 | weight | | | S5-02 | proforma invoice (PI), paper |
| | | S2-05 | commodity | | | S5-03 | customs doc., paper |
| | | S2-06 | perishable | | | S5-04 | shipper's decl. haz. mat. |
| | | S2-07 | specialty | | | S5-05 | T5 |
| | | S2-08 | ULD delivery | | | S5-06 | doc. For non-EU road del. |
| | | S2-09 | pallet delivery | | | S5-07 | AWB, electr. |
| | | S2-10 | loose delivery | | | S5-08 | proforma invoice (PI), electr. |
| **S3** | air | S3-01 | SPL to Europe | | | S5-09 | customs document, electr. |
| | transport | S3-02 | SPL to USA | **S6** | regional | S6-01 | within EU |
| | | S3-03 | SPL to Canada | | transport | S6-02 | within USA |
| | | S3-04 | SPL to India | **S7** | region. road | S7-01 | within region SPL |
| | | S3-05 | SPL to Japan | | transport | S7-02 | within NL |
| | | S3-06 | SPL to Far East/Austral. | **S8** | trans-shipment | S8-01 | incoming EU goods |
| | | S3-07 | SPL to Mid Atlantic | | | S8-02 | outgoing EU goods |
| | | S3-08 | SPL to South Atlantic | | | S8-03 | pickup of gds at agent |
| | | S3-09 | SPL to Africa | **S9** | AoG | S9-01 | regional road transp SPL |
| | | S3-10 | Europe to SPL | | | S9-02 | regional road transp NL |
| | | S3-11 | USA to SPL | | | S9-03 | regional road transp D |
| | | S3-12 | Canada to SPL | | | S9-04 | regional road transp F |
| | | S3-13 | India to SPL | | | S9-05 | regional road transp GB |
| | | S3-14 | Japan to SPL | | | S9-06 | hld NL outside reg. Hrs |
| | | | | | | S9-07 | hld USA outside reg. Hrs |

**Table 4.3: Overview of service elements**

**Definition of production elements and linking them with service elements**

The next step was to define the production elements for each of these categories, i.e. the operational materialization of the previously defined service elements and linking them together. The materialization indicates the direct connection between what a customer is asking and how these demands are fulfilled. Although we could use the service element categories of Distribution, it was found they made no direct link between these service elements and the actual order fulfillment. Production elements themselves were not used at all within the organization. Even more, the use of these elements proved to be somewhat cumbersome to *Carrier* managers directly involved in the study. The intermediate step between service elements and the modular process structure seemed an unnecessary step to them.

A number of other noteworthy issues came up during this process, which are depicted in figure 4.9.

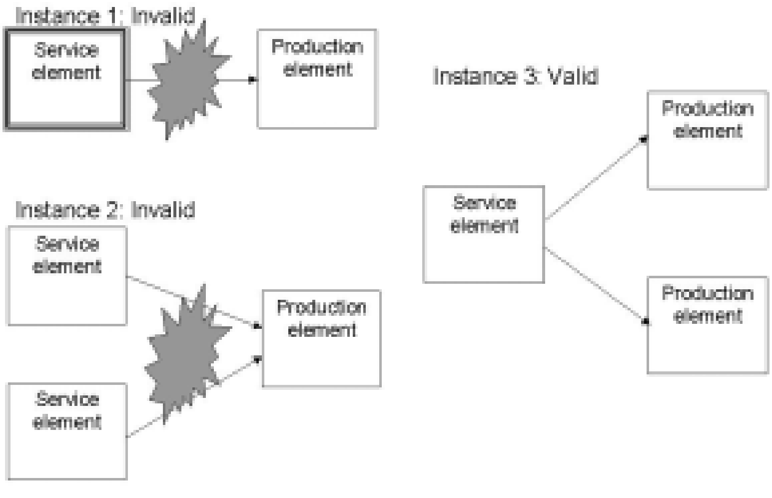


**Figure 4.9: Translation from service elements into production elements**

The double borderline of the service element in instance 1 indicates that it concerns a special type of service element, which was not translatable into one or more production elements. The nature of these elements, although relevant for the exact way the order is fulfilled, prevents a direct translation in production elements. Most of these elements could be found in the *Shipment info* category. Examples are: point of departure, destination, volume, weight and type of goods. In his thesis Hoogeweegen also had to deal with this problem, but he simply stated that these elements were either not of interest in the calculation of operating and transaction costs or irrelevant because all of his cases dealt with the same type of goods (a single pallet of commodities). We tend to disagree with these arguments, based on the findings in our case study. Volume and weight, for instance, often do strongly affect the engineering of the chain when the type of transport (regular or courier) needs to be chosen. Obviously, point of departure and destination cannot be neglected either. Therefore, we want to introduce *conditional service elements*, which could be used to (partly) solve this problem. Conditional service elements are, just as ordinary service elements, customer requirements. They however, do not directly require some activity to be executed, they only limit the number of possible translations of other – ordinary – service elements into production elements. The previously mentioned untranslatable service elements, such as destination, weight and point of departure, are all examples of conditional service elements.

The second instance is perhaps even more important and significant for the validity of the MND logic model. It concerns the instance when for some reason two selected service elements must be translated into one production element. A straightforward example is the selection of *Electronic document preparation* and *Prepare Airway Bill*, both from the category *Paper work*. This would lead to one single production element, namely *Prepare electronic Airway Bill*. Other examples are: two main reasons cause this problem to occur. First, the interdependence of two or more service elements causes difficulties in their translation in production elements. Solving this dependency is almost impossible. Introducing the condition that all service elements *must* be independent can hardly be sustained in practice. Moreover, customers often do (or only *can*) select certain service elements because they already did select certain others. Second, the first service element concerns a *'How'*, the second a *'What'* question. The 'How' service element in fact already specifies the way the 'What' service element should be translated in one or more production elements. One could solve this problem by introducing a clearer typology in service elements, which would (partly) solve this problem. An idea could be to formally distinguish between 'How' and 'What' type of service elements. Malone et al. (1997) already tried to do something similar with the Process Interchange Format (PIF) model (Lee et al. 1997) and the accompanying handbook of organizational processes. Another solution could be to distinguish between core and supplementary service elements as suggested by Lovelock & Yip (1996). Most important however for now is the finding that the service elements need to be independent for MND to work which is hard to achieve in practice and that a typology of service elements seems to be required as well.

Anyhow, while these proposed changes were not yet implemented in MND and *Erasmus in Chains*, many of the initially defined service elements, production elements and their linkages had to be redefined such that only the third instance of figure 4.9 would occur. This greatly affected the reliability and operational validity of MND. In addition to this point, it was found that in the air cargo industry the possible influence of the shipper's selection of service elements on the actual process structure is low. Transport chains are rather fixed, with a predetermined number of steps to be taken (e.g., figure 4.7 which depicts the steps of a regular order) in a relatively fixed order. The customer can hardly influence this structure.

**Definitions of process modules**

With respect to the usability of the definition of a process module, 'an atomic or elementary unit of work, which has no externally visible substructure, which can be operated in different contexts and produces the same output when replicated or repeated', the following remark has to be made. In practice, this definition turned out to be difficult to work with. Especially, the atomic level of analysis of a process module could in practice mean that one has to define a process module in a (too) detailed manner. For instance, is the process module ‘drive from A to B’ *atomic* enough or should we further distinguish between ‘Open door’, ‘Step in car’, ‘Start engine’ etc? The relation between the level of detail of a process module and the objective of the application of the model is unclear. A strategic analysis of the processes would obviously require a far less detailed level of analysis than a more operations-based investigation. The question then, of course, is how one should determine the appropriate level of detail beforehand. In the literature, an answer could not be found either. For instance, according to Feitzinger and Lee (1997) breaking down the production process into independent subprocesses provides companies with the kind of flexibility that effective mass customization requires (Feitzinger & Lee 1997:119). Unfortunately, they do not provide an indication of the level of detail of such a subprocess. While the initial objective of the case study was also quite broad, i.e. ‘analyze current situation and formulate and assess a number of alternative process handling scenarios’, the level of detail of the different process modules became very inconsistent.

Furthermore, the condition ‘which can be operated in different contexts and produces the same output when replicated or repeated’ was hard to live up to. Whether a certain process module produces the same output each time it is executed, often *depends* on its context, e.g., other modules in the process, available technology, etc. Especially when one decides to resequence modular subprocesses (or modules) one needs to know whether another sequence still leads to the same, valid outcome (i.e. delivery of the product or service). An example of Benetton, again taken from Feitzinger and Lee (1997) could illustrate this. Benetton rearranged its sweater-manufacturing process. Instead of first dyeing the yarn into different colors and then knitting it into finished garments, Benetton changed the order of the dyeing and knitting subprocesses. The company dyed the uncolored sweater either when it received an order or when it had a better idea of consumer’s color tastes for that season. Benetton could only resequence the modules due to an emerging technology in the fashion industry that allows dyeing of already knitted sweaters.

**Organizations involved in order fulfillment**

To fill the data model we, among other things, needed to know which organizations were involved in the fulfillment of the orders. Most of the Dutch sub-contractors were partners or subsidiaries of Distribution and therefore it was not difficult to gather information from them. However, gathering specific information about sub-contractors in the US and other non-Dutch countries proved to be very difficult practically and financially. Therefore, this case was limited to Dutch-located organizations only. For the purpose of our case, validating MND, this has no significant impact however. Generalizability of the results is sufficient, while the actual scope of the case (with or without the US trajectory) proved to be largely independent of the validation process of (the empirical descriptive) MND.

According to the conceptual prescriptive MND model the sub-contractors offer production elements to the chain coordinator, who then tries to make the best selection out of the available production elements, based on the customer’s selection of service elements. During the MND modeling process we found however, that it could happen that a certain customer requires that a specific part of the order must be taken care off by a specific organization of this customer’s own choice. For example, a shipper wants the road transport to be carried out by its own trucking company. This is similar to the problem with the 'What' and 'How' types of service elements of the previous section, only this time it concerns a 'Who' service element. Again, MND does not make clear how to deal with such requests within the model, therefore we will come back to this in the concluding section.

**Assessment of the current situation: costs and throughput times**

The final part of the analysis was the assessment of the costs and throughput times for all orders. For this purpose, the remainder of the data model had to be filled. For each order, all process modules had to be found. Next, for each process module the resources required to perform the module had to be determined and for each resource its costs had to be found as well. The duration of each process module had to be estimated, under the assumption that no errors would occur during the fulfillment of the activity. Consequently, each process module had a deterministic throughput time. Collecting all data turned out to be a very laborious task, because only a few archival records did exist from which we could extract data. The accuracy and precision of the collected data is due to this practical problem somewhat limited.

For instance, estimating labor costs for all organizations under analysis was nearly impossible. We had to assume all organizations had the same salary levels. This has to do with the difference between supply chain costing (SCC) (Lalonde & Pohlen 1996) and 'pure' intra-organizational Activity Based Costing (ABC). The SCC approach employs the same techniques used by activity based costing in assigning resource costs to activities. The difference between SCC and ABC occurs when activities span firms or when costing other firms' activities. In the cargo industry, organizations work with tariffs for which they hire each other's services and charge their own customers. However, MND has the ambition to analyze and audit the costs of the entire process. This chain perspective causes almost insuperable practical problems. For instance, the exact costs of a sub-contractor are impossible to determine. Lalonde & Pohlen (1996) suggest the use of expert knowledge, work standards, and cost estimates to overcome this problem. The expertise required could be drawn from internal sources within the specific firm, consultants, or individuals with experience in the activities. The practical workability remains however awkward. In our case, although some data could be found, the reliability and accuracy of the data is in fact fairly low. This is because financial information sometimes just was not available or impossible to obtain because the organizations did not want us to check their books. In addition, the theoretical validity of the data model can be questioned because a chain coordinator is not interested in the actual costs of possible sub-contractors but mainly in their tariffs. Based on these tariffs it will then be decided which organizations will be contracted. Therefore, although Lalonde & Pohlen noticed the need for a supply chain perspective on cost analysis, within MND such an analysis could best be done from the perspective of one single organization, preferably the coordinator.

This indicates that an analysis with MND requires extensive preparations and data gathering before an assessment can be made. The quality of the assessment strongly depends on the availability of detailed data concerning business operations as is always the case with ABC (or SCC) analysis. MDN further requires formulation of modeling elements such as service and production elements, which makes the analysis even more laborious. However, one needs to consider whether such a detailed MND-analysis is actually required, desired or even possible in particular situations. During our case study we noticed that the level of detail, more or less enforced by the requirement of modeling process modules (i.e. atomic activities) and using ABC as cost analysis tool, was too high for the purpose of the case.

### 4.4.4 Defining alternative scenarios

The next step within the case study was the definition of a number of (ICT-enabled) redesign options. In this section, this process will be described. First, a short discussion follows on who should formulate the alternatives. Then we elaborate on the impact of ICT and the way MND could support the decision-maker in defining ICT-based alternative scenarios and subsequently analyze them. The third part of this section briefly discusses a number of alternatives that were formulated in the case.

**Formulation of alternative scenarios**

MND itself does not give any concrete guidelines (or algorithms) how improvements could be made. Only the conceptual prescriptive part of MND gives a number of very generic guidelines (see section 3.4.1). The decision-maker has to define the alternative scenarios itself, possibly based on these guidelines. *Carrier* managers approved of this by saying that the definition of alternative handling scenarios requires expert knowledge and experience. According to them, an analytical model such as MND cannot take over this role. Experts have to formulate these alternatives beforehand and then you can use a method such as MND to check the profitability of such an alternative.

Some Operations Research methods exist however, which could contribute to the automatic formulation of alternative scenarios. One of these methods is the method of 'Crashing the Project' or 'Crashing the Network' closely related to the Critical Path Method and PERT (Anderson et al. 1995). Crashing a project involves attempting to reduce the completion time of a project from the time determined by the critical path to a lesser amount of time by applying additional resources to reduce the time of the most critical elements. The method calculates the optimal (minimum cost) way to crash the project using linear programming. Adding this method to (the empirical descriptive) MND could increase the operational validity of the model. A prerequisite for applying the 'Crashing the Project' method is the availability of the costs associated with decreasing the throughput time of the most critical elements. These costs were not known to either the researchers or the stakeholders in the case, so the method was not used.

**IT and EDI-based redesign guidelines**

Originally MND was developed to assess the impact of ICT applications, with EDI in particular. In the literature concerning ICT and EDI implementation and their impact on organization design, seven different redesign guidelines, divided in three different categories, have been localized by Hoogeweegen. The first category concerns Business Process Automation, i.e. local and small changes to intra-organizational processes. The second category is Business Process Redesign, which has a more profound impact on the organization. The third and final category affects the organization itself and its surrounding organizational network. The guidelines are summarized below.

| Category | No. | IT and EDI redesign guideline |
|---|---|---|
| **Business Process Automation** | ① | Support information storage and processing |
| | ② | Automate information exchange (internal and external) |
| **Business Process Redesign** | ③ | Reduce human labor in a process |
| | ④ | Treat geographically dispersed resources as though they were centralized |
| | ⑤ | Execute processes simultaneously |
| | ⑥ | Put the decision point where work is performed, and build control into the process |
| **Business Network Redesign** | ⑦ | Re-allocate activities among organizations |

**Table 4.4: IT and EDI redesign guidelines (Hoogeweegen 1997)**

During the case study, there was an attempt to translate these seven generic guidelines into more MND-related rules and guidelines. This proved to be very awkward and hard to do. Only guidelines number 5 and 7 were directly translatable in MND-terms, albeit they are not even EDI or IT-specific. Guideline 2 is translatable as well, but it is far too generic for direct use, next to the fact that it is an obvious and 'open door' guideline. The other guidelines could not be translated at all, while the bottom-up order perspective of MND is simply unsuitable for most of the guidelines. Decision points, information storage and (de)centralization of resources are not included in the MND perspective.

Therefore, guidelines 2, 5 and 7 were taken as starting point and subsequently four different levels of design alterations were formulated using the features of MND. These four levels could support the decision-maker in determining the impact of the redesign scenario. The following four levels of design alterations were defined.

1. Organizations:
   At this level, the organizations that take part in the process can be altered. It is possible to add an organization or to remove an organization from the chain and compare the newly defined scenario with the previous situation. It is also possible to re-allocate activities among the organizations in the supply chain.
2. The lay-out of production facilities:
   This level concerns the composition of the sets with available service elements, production elements and process modules. Elements and modules can be added or removed and the effects of these changes can consequently be assessed. For instance, an organization could decide to offer road transport to their customers as an additional service.
3. Resources:
   At this level changes are made in the availability of certain types of resources. An example of such an alteration is the introduction of EDI as a new resource.
4. Resource capacities:
   Finally, a scenario analysis can be done with different capacities of certain resources, for instance, the deployment of additional labor or machinery.

All of these levels can be addressed at the same time within a newly generated scenario and an alteration at a particular level could also effect the other levels, as is illustrated in the figure below:

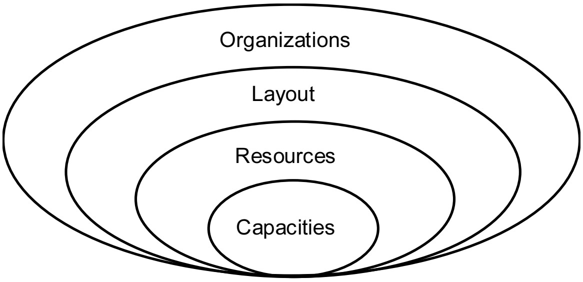


**Figure 4.10: Four different levels of design alterations**

Using these four levels as a reference framework, four different alternative designs were defined in the case study:

1. Tracking and tracing is carried out electronically with EDI, instead of by paper and fax;
2. The preparation of the Airway Bill is carried out electronically by Customs Handling, instead of on paper by the shipper itself;
3. The trucks from VD, a department within Distribution, are replaced by trucks from YT, another department within *Carrier*, not directly belonging to Distribution.
4. The number of trucks (VD) and forklift trucks available are increased. This alternative builds forth on the previous example with limited resources.

In the table below, the alternatives have been listed, together with the levels on which they have effect and for which orders they have been defined:

| **Alternative** | **IT Guidelines** | **Levels of impact** | **Applied on orders** |
|---|---|---|---|
| **1 – Tracking and tracing, electronically** | ② ⑤ | Lay-out<br>Resources | 1 till 3 |
| **2 – AWB preparation by CH, electronically** | ② | Organizations<br>Lay-out<br>Resources | 1a and 2a |
| **3 – Trucks (YT) in stead of trucks (VD)** | ⑦ | Resources | 1, 2 and 3a |
| **4 – Increased availability of trucks** | ⑤ | Capacities | 1b and 2b |

**Table 4.5: Overview of defined alternative scenarios**

### 4.4.5 Assessing the alternative scenarios

Although the savings in costs and throughput time were not very high (see appendix 1 for details), some improvements in costs and lead times could be made by sending electronic status messages or by electronic preparation of the shipping documents. The latter option, for example, enabled parallel, separated execution of both the preparation of the paperwork and the transport of the goods by the sub-contracted road carrier, thus saving time and money.

It is obvious that in fact only a few alternative scenarios were formulated, with a very limited scope as well. This is partly due to the lack of data concerning business operations outside the Netherlands, but this excuse is only partly valid. Part of the problem was the limited robustness of the model. We were not able to analyze very logistics-specific problems with our model. Inventory costs, response time, different transport routes, storage and handling capacities, loading schemes, etc. could not be analyzed. Moreover, although MND was especially developed to assess the impact of EDI, it does not take the actual content of an EDI-message (or any other piece of information) into account. Therefore, scenarios in which only different information was exchanged could not be compared with each other.

Furthermore, it turned out that an MND analysis was far too limited to analyze the full implications of the redesign scenarios. The conceptual and operational validity of MND appeared to be inadequate. This may be concluded from the fact that the involved *Carrier* managers decided not to implement any of the analyzed alternatives. They stated that many other issues played an important role in the design of transport chains, which were not included in the MND analysis (source: interviews held with *Carrier* managers involved and the presentation of results at a plenary meeting with several managers present[10]). First, the alternatives were not checked for their feasibility, i.e. whether a certain rescheduling of tasks still led to a valid customer order. Second, they stated that additional performance measurements were needed. For instance, the benefit of tracking and tracing mainly lies in the shipper's ability of checking the status of his goods, especially when he believes something has gone wrong with his shipment. Therefore, comparing a deterministic scenario without tracking and tracing with one with this functionality is useless. MND should at least be able to (ex ante) analyze the error-rate of certain network designs to really assess the need for and influence of, e.g., tracking and tracing.

## *4.5 Second case: Air Logistics*

### 4.5.1 Introduction and objectives

In the previous sections 4.4.3 till 4.4.5 we merely focused on the empirical descriptive part of MND, while this part of MND was used for assessing the current situation and a number of alternative scenarios. The second case within the air cargo sector is the Air Logistics case. The *Carrier* Cargo business unit Air Logistics aims at providing individually organized air transportation or distribution solutions. The unit is supporting customers that have a need for, and are prepared to pay for, the added value that the BU can provide from a list of possible offerings (also called service elements). When the package of service elements is determined, Air Logistics ensures the integrity of the flow of each customer's goods through the transportation and distribution chain, monitoring the flow from end-to-end. Air Logistics is researching, exploring and trying to realize commercial added-value opportunities such as door-to-door transport or airport-to-door transport. Part of the business unit's operations is managed by people who come from the Distribution unit, described in the previous section. Both units merged during the first case. The experiences of the people from Distribution (Distribution already acted as door-to-door chain coordinator for transporting spare parts and repair goods) could be useful for Air Logistics to explore the possibilities of door-to-door coordinating and transporting other type of goods as well.

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[10] Interviews took place in October 1997 by means of a semi-structured questionnaire, which can be found in appendix 2.

This study differs in a number of aspects from the Distribution case. These aspects are:

- Better specified case objective: analyze door-to-door chain coordination
- Multiple orders from only one customer
- Involvement of several non-*Carrier* organizations
- More focus on the end-customer, its specific requirements and the gap between supply and demand

In short, the situation under analysis proved to be a better situation to validate the conceptual prescriptive model of MND (see section 3.4.1), which focuses on the customization and flexibility of value chains and how this can be achieved. By looking at ZXV's specific requests (see next section), we can see that they exactly ask for a network that is designed in such a manner. The question then is how *Carrier* (and the other network members) could achieve this and whether the constructs of the empirical descriptive MND indeed are valid and useful for this purpose. We will therefore discuss the analysis of the current situation based on the conceptual prescriptive MND constructs. A detailed overview of costs and throughput times found in the case can be found in appendix 3.

### 4.5.2 Brief order description

One of the bigger customers (shippers) of Air Logistics is ZXV one of the world's biggest production factories in their industry. ZXV supplies automotive industries and other industries around the world with a large variety of their products. The company has strict service agreements with its own customers, such as a 72 hours delivery service of time critical parts. In the case of this urgent requests air transport is the best solution for worldwide and fast delivery. At the moment of our study, ZXV was looking for a single-stop logistic partner that could offer full door-to-door service from Europe to the United States within 72 hours. Air Logistics was one of the main candidates. The service they require is summarized below:

- **Break bulk operations**: segregating large, consolidated international shipments into small parcel/freight delivery direct to final USA locations, based on either ZXV-supplied data, or by using printed label information found on internal delivery packages.
- **Routing flexibility**: following specific carrier routing instructions from ZXV due to service, rates or customer requests.
- **Communications**: E-mail/Internet/possibly pure EDI regarding shipment dispatch details and tracking (i.e., B/L number, pieces, weight, charges and destination).
- **Billing flexibility**: either via assigned Customs Broker or directly to ZXV via EDI billing.
- **Reference capability**: ability to link USA shipments back to ZXV chosen internal reference numbers and back to arriving international AWB for tracking and billing purposes.
- **Performance reporting / summaries**: i.e. volumes, costs, and geographic history of activity.

The current transport chain, i.e. with *Carrier* only taking care of the airport-to-airport trajectory, can very briefly be described as follows. On every working day, 52 weeks a year, ZXV needs to transport its goods from its European factories (a total of five) to its American customers. Most of these goods are not time-critical and are therefore shipped by boat from Rotterdam to the US. The time-critical goods from the different goods all are shipped to Schiphol first, after which they are transported to Chicago in the US. In the US, the goods are further distributed to either ZXV's warehouses or directly to its end-customers.

### 4.5.3 Modeling the 'current situation'

This section is structured according to the constructs of the conceptual prescriptive MND. These constructs are:

- Temporary alignments of organizations, only getting together for the duration of one particular customer order;
- Modular product, process and network design;
- Presence of a central coordinator responsible for the fulfillment of the customer order;
- Direct translation (or materialization) of customer requirements into production to optimize the balance between what a customer is asking and what a chain is able to produce.

Together, these constructs should lead to cost-efficient customized value chains. We will discuss them below.

**Presence of a central coordinator**

In the 'current' situation, there is no unique, single chain coordinator who coordinates the entire chain for the end-customer. In fact, numerous coordinators exist. *Carrier* is the coordinator for the airport-to-airport trajectory and a forwarder takes care of the European transport from the ZXV factories to their Distribution center in a Dutch city, including the sea transport. Another forwarding agent coordinates the distribution of the goods in the US. Each of these organizations maintains contact with ZXV individually. Currently, the entire door-to-door coordination is in the hands of ZXV itself, 'supported' by three sub-coordinators. This finding complicated the modeling effort with MND, while MND assumes there is only one coordinator for each order which selects specific production elements from possible sub-contractors. However, ZXV first selects service elements itself from possible partners, after which these partners translate them into production elements and select the appropriate sub-contractors to supply these production elements. Therefore, instead of seeing just one supply chain coordinator translating customer requirements into production we see a couple of them. This means there should be just as many sets of service elements as well. Figures 4.11 and 4.12 below depict the 'two-stage' coordination in the current situation:

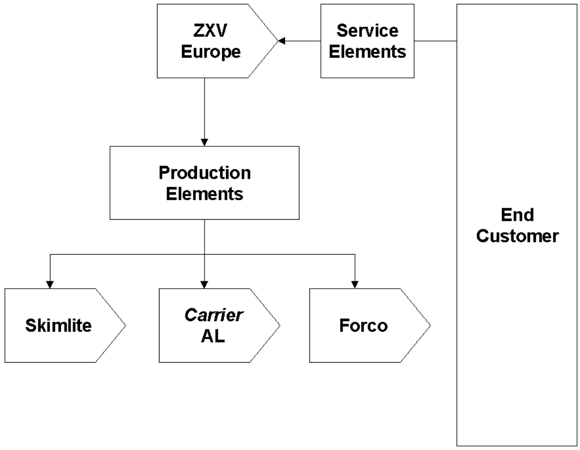



**Figure 4.11: Coordination by ZXV**

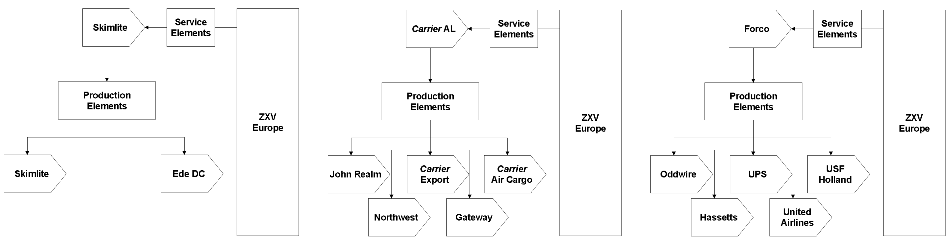



**Figure 4.12: Sub-coordination by three other organizations**

The question then rises whether the presence of a single coordinator is indeed conducive to increased supply chain flexibility. We could not use the empirical descriptive part of MND to analyze this. The 'sitting on the order' perspective of MND fails to include real coordination costs such as search costs (which sub-contractors shall I hire?) or switching costs (what does it cost to replace Forco by Pro Services in this case?). The actual design (or planning) of the network mostly happens beforehand as well, i.e. setting up contracts, negotiating with other parties etc. These coordination efforts are not included in the analysis either. It is also incapable of modeling the monitoring of the entire process, an important aspect of chain coordination according to *Carrier*.

Still, we can learn something from our analysis of the current situation about the way the network is coordinated and whether this leads to more flexibility. Analysis of the modeled orders (for detailed results on costs and throughput times, see appendix 3) made clear that the current chain coordination is not very efficient. This was mainly caused by a lack of communication between the organizations. The current transport chain may be characterized as a sequence of individual, independent nodes, instead of a network of cooperating organizations. Hardly any information is shared with other organizations. Moreover, information technology to support the communication between the organizations is hardly used. The first example to illustrate this notion is the booking process. ZXV books their orders in several ways (using different communication media) to several organizations (*Carrier*, Skimlite[11]). ZXV uses the facsimile machine to make *Carrier* bookings, but they use EDI links to make Skimlite bookings (road transport). The booking process is not very efficient, because the booking information is not shared or communicated to all participating organizations. The second example is the labeling process. ZXV initiates the chain and first labels the ZXV freight. However, none of the participating organizations uses these labels. All chain organizations make information labels for their own chain part.

All of this may be happening because chain coordination is delegated to three different coordinators. Another reason for the lack of cooperation may be the reluctance of the participating organizations themselves. According to Narus & Anderson (1996) organizations feel threatened by new cooperative arrangements, because they stand to lose long-established functions, responsibilities, and relationships. Forco is one of the organizations in the ZXV chain that are afraid to loose their position. According to Lalonde & Pohlen (1996), the lack of cooperation could be solved with power that is the driving force in supply chain relations. ZXV has cut the power into bits, because she delegates the power to three other coordinators. This results into a situation with no empowered organizations. No cooperation will take place and thus no integration and coherence of business processes to accomplish lower costs and shorter throughput times will occur.

In light of the conceptual prescriptive MND, the following may thus be concluded. The analysis of the ZXV transport chain showed that the current door-to-door chain is not efficiently organized. The chain coordination is delegated to more than one organization. This results into a non-transparent network of cooperating organizations. The less transparent network results into chain bottlenecks caused by inadequate communication links, bad connections between different transport routes, wrongly supplied information about weight, volume etc. or simply human mistakes. The empowerment that is needed to design integrated transport chains is cut in bits. The presence of a central coordinator may improve the flexibility and efficiency of the transport chain.

**Direct translation (or materialization) of customer requirements into production**

When discussing direct translation of customer requirements into production specifications, we obviously need to define who the customer actually is. For *Carrier*, this was ZXV itself. *Carrier* stated they were not particularly concerned with the customer behind ZXV, the end-customer of the bearings supply chain. In this bearings chain however, the transport is only a part of the total process next to manufacturing, assembly, sales etc. This also affects the definition of door-to-door. *Carrier* only had limited knowledge of the exact definition of the precise start and end-point of the 72 hours transport chain. This further complicated our analysis, while we could in fact ‘choose’ between two end-customers: ZXV or ZXV’s customers. Mainly for practical reasons (ZXV has thousands of customers in the US,) we chose the first option, although we realized that the latter option would have been the most challenging.

[11] Not only ZXV is a fictitious name, the other names are not the real ones either.

Table 4.6 below indicates the specified service elements offered by *Carrier* as coordinator of the airport-to-airport trajectory. Furthermore, the production elements have been added that materialize each of the service elements, together with the organizations which take care of these elements. They concern a number of organizations in the Amsterdam Airport and Chicago O'Hare (ORD) area. A division has been made in good-flow and information-flow specific elements just for reasons of clarity. Difficulties during the definition process were, if possible, avoided by defining all elements such that only instance number 3 of figure 4.9 did occur. Elements belonging to the other instances were omitted from the analysis (de Graaf 1999).

| Service elements | Production elements | Provided by |
|---|---|---|
| **Good flows** | | |
| Road transport | Pick up at Ede | John Realm |
| | Road transport Ede-SPL | John Realm |
| | Delivery at SPL | John Realm |
| Export handling | Storage of goods | *Carrier* Cargo |
| | Assembly of goods (Ede with Gothenburg goods) | *Carrier* Cargo |
| | Load plane | *Carrier* Cargo |
| Air transport | Flight SPL-ORD | *Carrier* Aviation |
| Import handling | Unload plane | Northwest |
| | Store goods | Gateway |
| | Transport goods to broker | Gateway |
| **Information flows** | | |
| Order booking | By telephone | *Carrier* Customer Service |
| Customs handling | Prepare customs documents | *Carrier* Cargo |
| | Clearing of goods | Customs SPL |
| Travel documents | Prepare Airway Bill | *Carrier* Cargo |
| | Prepare Cargo Manifest | *Carrier* Cargo |
| Labeling | Label goods at SPL | *Carrier* Cargo |
| Tracking and Tracing | POD at SPL | John Realm |
| | POD before departure | *Carrier* Cargo |
| | POD after arrival | Northwest |
| Invoicing and billing | Facsimile | *Carrier* Customer Service |

**Table 4.6: Set of service elements of Air Logistics**

We only had limited and second-hand knowledge of the exact service elements offered by the other coordinators to ZXV. The following set of service elements could be defined for the European forwarder Skimlite.

| Service elements | Production elements | Provided by |
|---|---|---|
| **Good flows** | | |
| Road transport | Pick up at factory Italy | Skimlite |
| | Pick up at factory France | Skimlite |
| | Pick up at factory Germany | Skimlite |
| | Deliver goods at Ede | Skimlite |
| | Storage of goods | Ede Distribution Center |
| | Transport goods to Rotterdam | Skimlite |
| Sea transport | Sea transport R'dam-Chicago | Unknown |
| **Information flows** | | |
| Order booking | By EDI | Skimlite |
| Travel documents | Prepare T5 | Skimlite |
| Labeling | Label goods at factory France | Skimlite / ZXV |
| | Label goods at factory Italy | Skimlite / ZXV |
| | Label goods at factory Germ. | Skimlite / ZXV |
| | Label goods at Ede | Ede Distribution Center |
| Tracking and Tracing | Unknown | |
| Invoicing and billing | Electronically | Skimlite |

**Table 4.7: Set of service elements of Skimlite**

The third set consists of the service elements Forco offers to ZXV, including the production elements and the sub-contractors of Forco who provide these elements.

| Service elements | Production elements | Provided by |
|---|---|---|
| **Good flows** | | |
| Import handling | Store goods | Forco |
| | Break down goods | Forco |
| Road transport US | From Hatchroad to Forco | Oddwire |
| | From Forco to end-customer | UPS |
| | From Forco to end-customer | USF Holland |
| | From Forco to back airport | Hassetts |
| | From airport to end-customer | United Airlines |
| **Information flows** | | |
| Customs Handling | By Automatic Broker Interface | Forco |
| | Pay import taxes | Forco |

**Table 4.8: Set of service elements of Forco**

Returning to the conceptual prescriptive MND the following may be concluded concerning the validity of this construct (direct translation of customer requirements into production) within the case study. First, the possibility and applicability of translating the construct into empirically useful guidelines or methods. In this respect, it was noticed that within the air cargo industry and within *Carrier* Cargo in particular this issue has gained increased interest. A proof of this trend was the development of the so-called VALUE Product Verification and Engineering tool by *Carrier*. Largely based on the MND construct 'direct translation from requirements into production', *Carrier* decided to develop a Product Verification and Engineering Tool intended for business unit personnel who wish to use to tool to engineer and verify products. The tool should answer the following questions:

- Where can the product be offered?
- When can the product be offered?
- How can the product be offered?

Just as within MND, a product is defined in terms of service elements, divided in the following types: transport, handling, information and finance. Moreover, service elements can be further broken down into production elements, i.e. specific activities that must be completed to produce a service element. Subsequently, two different approaches are available. The first, *Outside-In*, is an interactive approach where the user specifies the origin station, the destination station, the required service elements, the required throughput time and a one-week test period. Next, the tool will calculate and display, if possible, a set of feasible *routing options* for each day of the test week. The other approach, *Inside-Out*, is a batch approach. Here, the user specifies only the required service elements, the required throughput time and a one-week test period. The tool then will calculate and display, for each feasible combination of *Carrier* Cargo origin and destination stations, the number of feasible routing options for each day of the test week.

In other words the development of the VALUE tool within *Carrier* confirms the validity of the 'direct translation' construct of the conceptual prescriptive MND. One should however take into consideration that the (causal) relation between direct translation and value chain flexibility cannot be confirmed directly in this manner. The main reason for *Carrier* to develop the tool (and to apply MND initially) was to be able to verify to feasibility of their product portfolio they offer their customers. The direct result of the use of the construct 'direct translation' is merely a reliability check: are we indeed capable of delivering what we promised? The indirect or follow-up effect however, may be increased flexibility and affordable customization offered to the *Carrier* customers.

**Temporary alignments of organizations**

Empirical findings in both cases carried out in the air cargo sector showed just the opposite of dynamic networking and temporary alignments of organizations. These findings include the ongoing efforts of transport organizations to merge with, ally with or take over other organizations, as described in specialist literature such as *Nieuwsblad Transport* (Journal of Transport) or Internet-sources such as www.cargoweb.nl. *Carrier*, for instance, tried to initiate alliances with other (European) airlines to increase their transport network and achieve scale economies. Ideally, in due time the cargo sections of these organizations should merge in one, globally operating cargo organization.

Furthermore, *Carrier* itself stated that their flexibility merely was achieved by its ability to deal with errors or mistakes during the process or other exceptions that would occur compared to regular business. They tried to achieve this by making as many agreements and contracts as possible. In this respect they prefer static planning and close relationships and alliances with other organizations. In the case of static planning the engineering of the transport chain is a one-time effort in which all the necessary steps are determined and allocated among sub-contractors. Agreements are made with the customer about picking up and delivery at fixed times. Flexibility can then be accomplished within these partnerships, not by dynamically switching between partners or sub-contractors. Two other types of planning exist at *Carrier*. The second type is dynamic planning. In this case known suppliers and sub-contractors are used to construct the transport chain, but this time it concerns ad hoc and special planning of the chain. The third and final type of planning is called Cargo Cowboy planning. In this case, it concerns an unknown destination with unknown sub-contractors that only need to be sub-contracted for one particular occasion.

Most of *Carrier*'s planning is static planning (ca. 95%), around 4.9% concerns dynamic planning and only a very small percentage involves the cowboys. *Carrier* really prefers static planning, for which they can plan their capacity in advance, disperse demand peaks etc. They claim that their shippers also profit most from this type of planning. When *Carrier* knows the production and manufacturing forecast of its shippers, it is able to plan its shipments way ahead, thus saving costs for both parties involved. This in fact contradicts the notion that temporary interorganizational alignments prevail with respect to cost efficient flexibility.

Furthermore, the use of dedicated, non-compatible, information systems for booking, tracking & tracing, invoicing etc. further confirmed this. Therefore, the construct could not be translated into useful guidelines and methods. It seems that the air cargo industry is not profited by temporary alignments, but prefers fixed and stable alignments and alliances instead. This may be due to a number of factors

- The scarcity of landing slots at airports. This forces the cargo companies to enter into alliances with other companies and sub-contractors to gain as many slots as possible. The consequence is that one cannot easily switch from one sub-contractor to another.
- Lack of central coordination structure. A dynamic network a temporary alignments requires some sort of broker or coordinator who takes care of the engineering and monitoring of the chain (Miles & Snow 1986). The position of the majority of the participants in the air cargo industry is as such that no one can fulfill this role or is allowed by the other parties to take care of it, due to fierce competition.
- The historically fixed structure of the air cargo industry (see section 4.4.1) prevents the use of a more dynamic and varied structure. The sequence of the activities is very fixed as well as the specific parties (like customs) involved in the network.

**Modularity**

The next question is whether the concept of modularity as used in the conceptual prescriptive MND is theoretically sound and appropriate and whether it can be translated into empirically useful guidelines and methods. Next, if so, whether the use of modularity in practice could lead to higher flexibility. The first question will be elaborated on first.

Modularity has been incorporated in MND on three different levels. Obviously the process modules refer to modularity of processes, i.e. decomposing entire processes into modular activities. Hoogeweegen refers in his definition of a process module, among others, to Pine et al. (1993) and McCutcheon et al. (1994). The latter merely refer to modularity of products and services. This type of modularity can be found in the service elements. Next to these two types of modularity, Hoogeweegen states that within MND organizations are viewed as modular entities (Hoogeweegen 1997:64). These organizations participate in temporary supply chains to fulfil customer orders. Although Hoogeweegen does not further elaborate on this notion, this is in fact a third type of modularity: modularity of supply chains. Fine (1998) also distinguishes between these three types of modularity. In contrast with Hoogeweegen Fine does give the antonyms of all three types. Product architectures can be integral or modular, just as supply chain architectures.

When we define modularity as the possibility of dividing a product, process of chain into distinct, but interrelated, modules we may conclude that modularity in combination with direct translation of customer requirements into production is very useful. By means of using modularity, one is able to define a product (or service) as the total of many different modules or components. The same holds for production processes required to fulfill each customer requirement, therefore the direct link can be established between requirements and production. In this respect, one can also argue that dividing a network and/or individual organizations into distinct modules can be useful for determining *who* should take care of the fulfillment. However, modularity also deals with the coupling between the modules by means of the interfaces. When one decides to divide a product, process or supply chains into distinct modules one should also deal with the way these modules come together and how they interact. Will the total composition of the modules indeed still function and work properly as intended? Perhaps a more integral approach is preferred in certain circumstances. Such considerations are not included in MND initially, but they need to be dealt with when one tries to make a link between modularity and value chain flexibility.

Therefore, to actually validate modularity in respect to value chain flexibility one should at least be able to select the appropriate degree and type of modularity or its opposite, integrality. Only then will one be able to validate the contribution and appropriateness of the concept of modularity in a certain situation. While such a typology of modularity is lacking in MND, we are unable to make statements about the benefit of modularity in our cases. What is needed is a assessment technique or criterion to determine this added value of (some degree of) modularity in comparison with its opposite. This topic will be one of the central issues in the next dissertation modules, chapters five to eight of this dissertation.

### 4.5.4 Definition and assessment of alternative scenarios

At the time of the case study, *Carrier* only coordinated the airport-to-airport trajectory from Ede to Chicago. This includes both road and air transport. Other parties than *Carrier* coordinate the other parts of the transport process. The central coordination of these parties, including *Carrier*, is currently done by ZXV itself. However, ZXV has indicated it maybe wants *Carrier* to take over this role. This means that *Carrier* would become responsible for the monitoring and coordination of the entire chain, starting at the European ZXV factories and ending at ZXV's customers or distribution centers in the US.

*Carrier* itself formulated a number of ideas and objectives with respect to the full door-to-door coordination of the ZXV transport from its European factories to its US distribution centers and end-customers. These ideas were formulated in the following areas:

1. Choice of sub-contracted parties
2. Customer-related information services, e.g. tracking & tracing and invoicing
3. Process-related information exchange by electronic means
4. Choice of transport routes, pick up points and hubs

An attempt was made to define three different alternative scenarios that would not only incorporate most of the previous four issues, but they should also enable us to further analyze the validity of the (conceptual prescriptive) MND constructs. The three scenarios are (de Graaf 1999):

1. One chain coordinator (Air Logistics) instead of three
2. Additional use of ICT
3. Increased chain customization

The third scenario is an extension of the combination of scenarios 1 and 2, i.e. one coordinator and additional ICT usage.

**Scenario 1: One chain coordinator**

This scenario implicates that *Carrier* Cargo collects not only status information, but invoices and initiates one time labeling as well. In this scenario, it is assumed that the coordinator is able to manage the chain based on the collected information. The customer communicates with only one organization that knows everything about the entire transport chain. This leads to a more efficient transport chain, because fewer activities have to be performed. Table 4.9 presents the results.

| | Total time | Throughput time | Costs |
|---|---|---|---|
| **Current chain for the order France to Crossville** | 3165 min | 2940 min | ƒ 3570 |
| **One TSCC chain for the order France to Crossville** | 3145 min | 2910 min | ƒ 3535 |
| **Difference** | 20 min | 30 min | ƒ 35 |
| **Current chain for the order Sweden to Crossville** | 2850 min | 2735 min | ƒ 3428 |
| **One TSCC chain for the order Sweden to Crossville** | 2821 min | 2715 min | ƒ 3386 |
| **Difference** | 29 min | 20 min | ƒ 42 |

**Table 4.9: Time and cost differences for the one-coordinator scenario**

These results teach us that the transport chain with one coordinator has shorter throughput times and lower costs. The throughput time decrease is caused by better communication and chain transparency. The communication is improved because the information is shared by more than one organization. The coordinator is responsible for the information sharing process. This means that the coordinator collects the POA (Proof of Acceptance) and the POD (Proof of Delivery) information with the support of fax and telephone (in contradiction to the next example). The central information collection provides the coordinator insight into the chain. Moreover, the invoices will be sent to the coordinator too. This means that the coordinator maintains the central information system of the transport chain. The cost profit is caused by fewer activities. The three chain coordinators in the current situation cause inefficient activities, but also execution of redundant activities, such as double labeling.

**Scenario 2: Additional ICT usage**

This scenario is based on widespread ICT usage in the transport chain. The four problematic information processing business processes (tracking & tracing, labeling, booking and performance reports) will be supported with ICT. The booking process is supported with ICT usage with the application of Internet booking. The customer is able to book the order in one time. The clearance process is also digitized. The freight is cleared electronically to the Dutch and US customs. This clearance process is supported with the electronic airway bill. In this manner, the informational flow is disconnected from the physical flow. Furthermore, the billing process is also digitized. The participating chain organizations will send the bills directly to ZXV, the customer. This means that three coordinators manage the transport chain. Table 4.10 presents the results.

| | Total times | Throughput times | Costs |
|---|---|---|---|
| **Current chain for the order France to Crossville** | 3165 min | 2940 min | ƒ 3570 |
| **IT based chain for the order France to Crossville** | 3177 min | 2649 min | ƒ 3612 |
| **Difference** | -12 min | 291 min | - ƒ 42 |
| **Current chain for the order Sweden to Crossville** | 2850 min | 2735 min | ƒ 3428 |
| **IT based chain for the order Sweden to Crossville** | 2887 min | 2478 min | ƒ 3490 |
| **Difference** | - 37 min | 257 min | - ƒ 62 |

**Table 4.10: Time and cost differences for the IT usage scenario**

The results show that the throughput time decreases, while total time and total costs increase. The disconnection of physical and informational flows causes the shorter throughput-times. The physical process is uncoupled from the informational process. This means that the throughput times only depend on the length of the physical processes. The cost increase is mainly caused by the assumption that computer usage requires employees with more knowledge, which are more expensive.

### Scenario 3: Increased customization

Most important to the shipper is that the transport chain meets his or her requirements. This may implicate that the transport chain should be highly customized to the customers' demand. The current ZXV chain is highly customized, because all chain organizations customize their processes to satisfy ZXV. The objective of this customization scenario is to customize the transport chain with standardized elements. This is called customization through standardization. The customization scenario is a combination (and extension) of the previous two scenarios and it is described below.

This scenario assumes the following. A ZXV Internet booking at the *Carrier* Cargo Internet site initiates the transport chain. The information is stored in one information system. The information system provides pre-alerts for the participating organizations. All chain organizations are able to forecast their capacity and in some cases, they are able to execute their work. The information that is put in the electronic airway bill will also be sent to the other chain organizations (the electronic airway bill is already used by, e.g., Canadian Airlines). The bills or invoices will also make use of the central information system. The invoices are sent electronically to the chain coordinator. Moreover, the organizations along the transport chain scan the incoming and outgoing freight to retrieve digitized POA and POD information. These points provide the information that enables the coordinator to analyze the transport chain. Furthermore, the customer can be provided with status information. The information flow is now completely disconnected from the physical flow. This means that the freight does not have to wait for customs clearance in Europe and in the USA. The results are presented in the table 4.11.

| | Total times | Throughput times | Costs |
|---|---|---|---|
| **Current chain for the order France to Crossville** | 3165 min | 2940 min | ƒ 3570 |
| **Customization chain for the order France to Crossville** | 3152 min | 1110 min | ƒ 3573 |
| **Difference** | 13 min | 1830 min. | - ƒ 3 |
| **Current chain for the order Sweden to Crossville** | 2850 min | 2735 min | ƒ 3428 |
| **Customization chain for the order Sweden to Crossville** | 2890 min | 985 min | ƒ 3425 |
| **Difference** | - 40 min | 1750 min | ƒ 3 |

**Table 4.11: Time and cost differences for the customization scenario**

The results show that throughput times decrease significantly, while total costs are nearly the same. This decrease is realized through one chain coordinator and IT usage in the chain design. The central information that is managed by the chain coordinator leads to a more transparent and a better manageable chain. The chain coordinator is able to monitor the transport chain from day to day. Moreover, the physical chain is now disconnected from the information chain. This means that the throughput times depend only on the total time of the physical processes.

The disconnection between the physical and informational flow requires usage of other resources such as computers, Internet connections and skilled employees. This may have impact on the organization selection. Not all organizations are able to make the investment or to have the skills. The installation and the development of a network of skilled organizations results into a more fixed network of organizations. The selection of organizations will be based on competencies and no longer on historic relationships. The chain coordinator *Carrier* could build a network of capable organizations that are able to execute their part of the transport chain.

**Reactions**
Despite the promising results of especially the third scenario, *Carrier* managers involved claimed that within the air cargo sector politics is far more essential than just some decrease in operating costs or throughput times. Especially when an alternative concerns one or more outside (non-*Carrier* related) parties, such as forwarders, decisions will primarily be based on political reasons. Even when an objective method such as MND can show the benefits for all parties involved, they did not believe that an organization would allow other organizations to take over (part of) their business, just for efficiency reasons. The only real decision-maker in the chain is the end-customer. Shippers decide whether to hire a particular organization. In this respect, they could see benefit in the use of MND to convince shippers of hiring *Carrier* for their transportation, in other words as a marketing tool (de Graaf 1999).

The initial objectives of the case, analyzing the current situation and defining a number of alternative handling scenarios with Air Logistics as chain coordinator, could nevertheless be achieved to a certain extent. We were indeed able to provide additional insight in the problems and bottlenecks of the handling processes and to define and assess a number of improvement scenarios. However, because we also ran into numerous problems with MND itself the reliability and operational validity of the outcomes need to be taken into account.

## *4.6 Conclusions: Validating the Empirical Descriptive MND*

The following two sections will summarize the conclusions drawn from the two cases in the air cargo industry and the development of Erasmus in Chains. In this section, 4.6, the empirical descriptive part of MND is discussed, while 4.7 contains the findings on the conceptual prescriptive MND. In both cases, the conclusions are grouped according to the formulated validation model of section 3.7. In section 4.6.1, logical validity of MND is described. Then in section 4.6.2 we elaborate on the data validity of the model, followed by an analysis of the general validity of the empirical descriptive MND. In section 4.6.4, we discuss the face and interface validity of the model.

### 4.6.1 Logical validity of empirical descriptive MND

Logical validity consists of two components, which are defined as follows:

**Analytical validity** = appropriateness of relations in logic model
**Theoretical validity** = whether the underpinnings of the model are theoretically sound

We will discuss both types of validity for each of the constructs of the empirical descriptive MND. The constructs, which together make up the logic model of the empirical descriptive MND, are again given in the figure below:

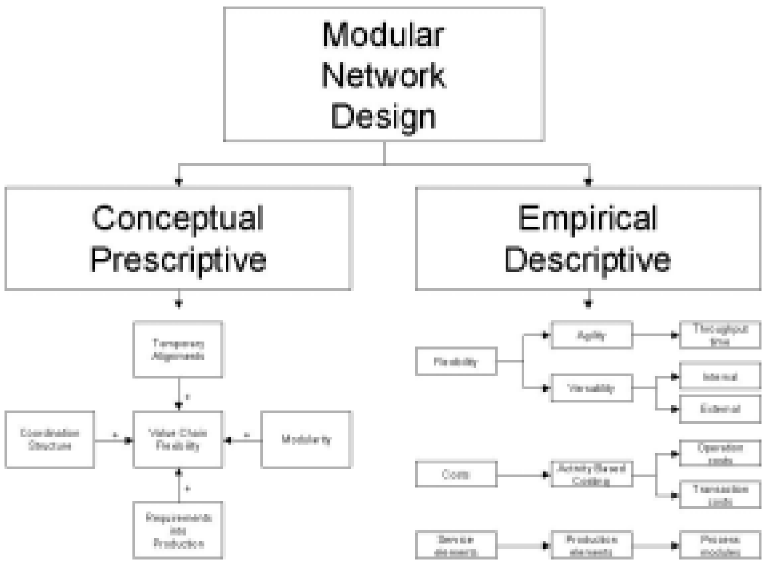



**Figure 4.13: The two MND perspectives**

**Assessing flexibility**

Flexibility has been divided in two constructs: agility and versatility. The analytical validity of both terms is appropriate (see Evans 1991, Bahrami 1994, Volberda 1996), but the operationalization is theoretically invalid. Agility 'simply' expressed as throughput time is inadequate (e.g., Goldman, Nagel & Preiss 1995). The operationalization of versatility is also inadequate and could therefore not be included in the DSS. Moreover, a dispute exists about the question whether both types of versatility (internal and external) should be maximized to ensure maximum flexibility. Hoogeweegen claims that both types should be as high as possible to ensure sufficient customization, while both Anderson & Pine (1997) and Piller (1999) claim that only external versatility should be maximized. Internal versatility on the other hand, should be as low as possible. Due to insufficient validity of the construct within MND, we are unable to establish which of the viewpoints is most valid. To summarize we may say that MND is, in the current version, not able to adequately assess the degree of flexibility of a value chain. More advanced and sophisticated measurements are required together with a strategic perspective, instead of the current operational one.

**Assessing agility: throughput times**
As mentioned above, agility has been operationalized as throughput time of an order. Next to the low theoretical validity of this operationalization, the following conclusions can be drawn. Determination of critical time of a deterministic flow is appropriate and theoretically sound, just as the calculation of total time by accumulating all individual activity durations; both are very straightforward calculations. Assessment of critical and throughput time in a deterministic manner has however a very low operational validity in the air cargo industry (and most likely in other industries as well). With the inclusion of the possibility to analyze the occurrence of delays, caused by insufficient resources, the operational validity has slightly increased. The question however, whether throughput time should be included at all in the model (analytical validity) is undisputed, especially in the air cargo sector. Throughput and delivery times are essential in this time-critical industry. One could only argue that the response time (the time between order placement and order fulfillment) should formally be included in the model as well.

**Assessing costs**
The appropriateness of assessing costs on supply chain level is undisputed. Whether one wants to assess the impact of ICT, analyze the costs of increasing flexibility or investigating mass-customization strategies, the need for a good assessment of the costs is apparent. Especially in the air cargo sector, where competition is mainly based on price-setting and cost-level this functionality is a high priority requirement for an assessment model.

Problems occurred however with the determination of costs on supply chain level (also denoted as supply chain costing by Lalonde & Pohlen 1996). The outcomes of a cost assessment are large dependent on the chosen perspective: chain perspective vs. single organization perspective. The costs of a certain organization do not correspond with the costs another organization makes to sub-contract them. The former are the costs needed for an ABC analysis costs, the latter are the tariffs charged by one organization to another (see problems with collecting and calculating costs in especially second case study). In the second study, it was concluded that within MND a cost analysis could best be done from the perspective of one single organization, preferably the coordinator. An alternative would be to get commitment of all members of the supply chain to carry out a supply chain costing analysis – practically, this may be impossible to achieve, especially in the highly competitive cargo industry.

When assigning costs to activities, no complete use is made of the ABC technique. This technique consists of five different building blocks to assign costs to activities (e.g., Turney 1996). MND only uses four, the ‘activity driver’ misses. Activity driver is a factor used to assign costs from an activity to a cost object. Cargo specific examples are pallets, containers, trucks or entire airplanes. This means, for instance, that it is difficult to analyze a single order that is split or consolidated during the fulfillment process, something that frequently happens in the transport sector. The current logic model of MND does not specify what to do in each of these instances. It should therefore at least be extended with the ‘activity driver’ building block – a straightforward and easy addendum.

**Logic for linking service elements, production elements and process modules**

No formal logic or architecture was available to determine the relationships between the MND modeling elements (mapping of service elements on production elements, sequencing the process modules etc.). The question arises whether such an architecture can be developed. Such an architecture will most likely be very case specific, such as *Carrier*’s own VALUE tool, but maybe a number of generic design guidelines can be developed. Pine et al. (1993) already stresses the need for such an architecture, which should enable costless, seamless, frictionless and instant linking of the elements. Van Asseldonk (1998:289) supports this view as well: ‘In practice, to achieve mass-individualization, managers first need to turn their processes into modules. Secondly, they need to create an architecture for linking them. The coordination of the overall dynamic network is even in modern supply chains often mistakenly centralized, while each module retains operational authority for its particular process. […] The only solution to combine high levels of heterogeneity with industrial cost-parity is to atomize the supply chain process into recombinant nodes, and make these nodes self-organizing, driven by client requirements.’ Keywords for that matter are self-organizing and adaptive, without a central authority present.

Another useful viewpoint on this matter comes from Larsson & Bowen (1989). They specifically focus on the link between the customer, the front-office and the back-office of (service) organizations. Depending on two factors - diversity of demand and customer disposition to participate - most attention should be paid to either one of these or to a link between them. The following figure illustrates both dimensions and their consequences for design.

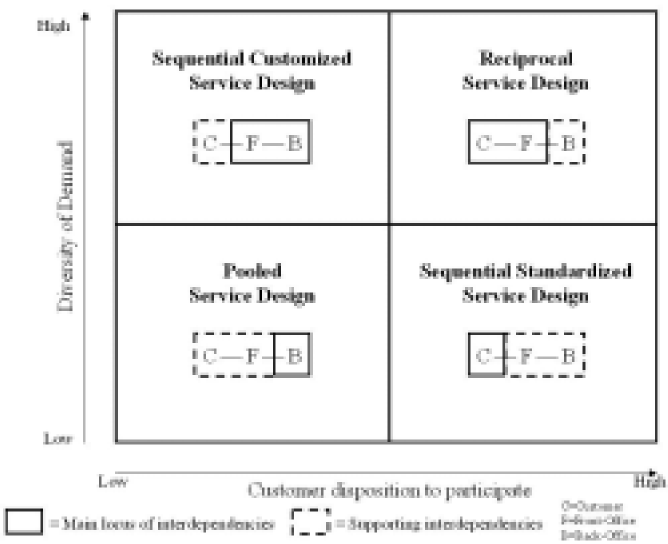



**Figure 4.14: Typology of service interdependence patterns (Larsson & Bowen 1989)**

For instance, when demand is very diverse and the customer has a high disposition to participate, the focus of the organization should be on the link between the customer and the organization's front-office. This leads to interactive service production between mainly customer and front-office employees. Examples of such organizations are mainly found in medical care, legal advice and higher education (Sasser, Olsen & Wyckoff 1978, Larsson & Bowen 1989). When both factors are low, most of the work may be allocated to efficient back-office operations composed of standardized interdependencies and decoupling from most front-office disturbances (Chase 1981, Larsson & Bowen 1989).

We learn from the work of Larsson & Bowen that an architecture for linking the different elements with each other must at least deal with two external factors: diversity of demand and customer disposition to participate[12]. This is further confirmed by the fact that Larsson & Bowen argue that Thompson's (1967) interdependence typology can be aligned in order of complexity (pooled ⇒ sequential ⇒ reciprocal) along the diagonal from bottom-left to top-right of their own framework. Hoogeweegen (1997) also used the work of Thompson to describe possible interdependencies between the process modules. It can thus be concluded that linking the different elements with each other has strong analogies with the organizational literature on coordination by, e.g., March & Simon (1958) and Thompson (1967). This literature however, has a mere internal focus, in the sense that it does not address the role of the customers in operations (Larsson & Bowen 1987).

Another interesting contribution on the subject of architecture and linking comes from the research on software and computing development. Computing infrastructures are expanding their reach in every dimension. New platforms and applications must interoperate with legacy systems. Those who design computer systems face difficult technology choices. As computers and networks become faster and cheaper, even interconnection standards must evolve. The question the industry wants to answer is how organizations can ensure that their mission-critical information systems are rooted in standards that will adapt to new hardware capabilities and software platforms.

The Object Management Group (www.omg.org) addresses this question with MDA, the Model Driven Architecture. MDA supports evolving standards in application domains as diverse as enterprise resource planning, air traffic control and human genome research. MDA separates the fundamental logic behind a specification from the specifics of the particular middleware that implements it. This allows rapid development and delivery of new interoperability specifications that use new deployment technologies but are based on proven, tested business models. Organizations can use MDA to meet the integration challenges posed by new platforms, while preserving their investments in existing business logic based on existing platforms. MDA provides an architecture that assures:

- Portability, increasing application re-use and reducing the cost and complexity of application development and management.
- Cross-platform Interoperability, using rigorous methods to guarantee that standards based on multiple implementation technologies all implement identical business functions.

[12] In the third research module both factors will indeed be included in our research framework on modularity and customization.

- Platform Independence, reducing the time, cost and complexity associated with re-targeting applications for different platforms.
- Domain Specificity, through Domain-specific models that enable rapid implementation of new, industry-specific applications over diverse platforms.
- Productivity, by allowing developers, designers and system administrators to use languages and concepts they are comfortable with, while allowing seamless communication and integration across the teams.

Elaborating further on the details of MDA would be outside the scope of this thesis. It may however be clear that this architecture may be very helpful in developing an architecture for linking the different elements of MND and subsequently, linking customer requirements with business processes. Such an MND architecture should ideally possess the same rigor and structuredness as MDA.

Another conclusion that may be drawn is that this way of modeling is not directly useful to analyze the gap between supply and demand, the so-called *black hole (*Sasser et al. 1978). Although *Carrier* managers saw the benefit of an MND analysis for this purpose and also the customization scenario of section 4.5.4 partly rejected this conclusion, thus far it is impossible however to compare different scenarios with each other on the evaluation criterion 'size of black hole'. Answering questions such as 'Has the *black hole* decreased for this scenario?' or 'Are we customizing better?' is not possible. The question is how this could be incorporated in the model. This may be done by including a measurement of customer value for each service element and thus determining the (financial) gap between both items (Delporte 2002). At the moment, the strength of this part of the logic model mainly lies in its general validity, especially conceptual validity (see section 4.6.3).

Furthermore, it turned out that translation of service elements into production elements is not possible for all types of service elements and their specific relations with production elements. For instance, weight, destination, volume etc. are very important in air cargo, but cannot be directly translated into production terms. Therefore, a specific demarcation and typology of service elements is required. *Conditional service elements* were already introduced in section 4.4.3, just as the distinction between 'How', 'What' and 'Who' service elements. This issue is related to the design of a linking architecture for the elements. A simple service element typology could be developed, helpful in assigning production elements to service elements. The typology uses the nature of the service elements to determine what type of 'satisfiers' are required. Table 4.12 depicts the service element typology and the accompanying type of production elements.

| Type of Service Element | Type of Production Element | Example |
|---|---|---|
| What | General specifications | Color, size, accessories etc. |
| How | Way of… | … delivery, production, etc. |
| Who | Organization specific | Dedicated supplier |
| When | Time specific | Delivery time |
| Where | Location specific | Production areas |

**Table 4.12: Allocation typology**

Five generic service element types are distinguished: what, how, who, when and where types. The first type concerns specifying the general product or service: 'What product or service do I want?' The other four mainly concern additional (value-adding) requirements which ask for additional activities. The who-type, for instance, allows the customer to specify which organizations, units or people should cooperate in the virtual organization. The coordinator on his turn is then limited in his choice of sub-contractors. Combinations of types are also possible. Express-delivery is an example of a how and a when-type of service element. A simple, straightforward typology such as this could be the first step to formalization of the allocation procedures.

### 4.6.2 Data validity

Data validity deals with the precision and accuracy required for the problem at hand. It consists of the following types:
**Accuracy** = A measure of the systematic bias in a piece of data or information
**Precision** = A measure of the random error in a piece of data or information
**Theoretical validity** = whether the construction of the data model can be justified in terms of established theory

Data validity strongly depends on the availability of reliable and accurate data to perform calculations and other analyses with the model at hand. During the application of both case studies it was found that a bottom-up focus of the model ('sitting' on the order) requires the estimation of single-order related costs. In practice this is hard to accomplish, causing each activity-based cost estimation to be less accurate and precise. Only when organizations keep full and detailed account of their costs will the modeling effort be more reliable. Estimating throughput times and duration of each activity deals with the same problem. Furthermore, collecting reliable and accurate data about the resources required to perform the process modules turned out to be very awkward.

Furthermore, no distinction was made in the data model between resources that 'disappear' after use and thus need to be replenished and ones that are only temporarily unusable but will become available again after some time. Obviously, this can easily be added to the data model.

Finally, MND could be benefited by more detailed guidelines and definitions about the required level of detail for the process modules in relation with the objective of the application. The absence of such guidelines could avoid over-detailed or over-generic analyses. This should increase reliability and precision of the data collected. Especially in the first case with a very broadly defined objective ('improve process performance') this was a significant problem.

### 4.6.3 General Validity

General validity concerns the validity of the model or system as a whole, rather than the individual elements of it. Five different types are distinguished:

**Conceptual validity**

Conceptual validity refers to the question whether the system is appropriate to use for the problem under investigation. The work of Kettinger et al. (1997) will be used to determine the conceptual validity of MND in each case, together with a qualitative description of the problem at hand and its fit with the MND functionalities. Kettinger et al. developed a stage-activity framework to map individual BPR tools and techniques onto and verify their support for each activity (see section 3.4.3 for more details on this framework). Based on the experiences of the two studies and the development of *Erasmus in Chains* we can now map MND on this framework as well. Table 4.13 depicts a number of MND-related tools and techniques, together with MND itself.

| Stage | 1 | | | | 2 | | | | | 3 | | 4 | | | | 5 | | | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Activity | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 |
| Activity Based Costing | | | | | | | | | | ■ | ■ | | ■ | | | | | | | ■ | |
| Brainstorming | | ■ | ■ | | | | | | | | | ■ | | ■ | | | | | | | |
| Data Flow Diagramming | | | | | | | | | | ■ | | ■ | ■ | | ■ | | | | | | |
| Hierarch. Colored Petri Nets | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| IDEF $_{0, 3, 6}$ | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| IDEF $_{1, 1X, 4, 5}$ | | | | | | | | | | | | | | | ■ | | | | | | |
| IDEF $_{2}$ | | | | | | | | | | | | ■ | ■ | | | | | | | | |
| Information Technology Anal. | | | ■ | | | | | | | | | | | | | | | | | | |
| Process Flowcharting | | | | | | | | | | ■ | | ■ | ■ | | | | | | | | |
| Simulation | | | | | | | | | | | | ■ | ■ | | | | | | | | |
| Value-Chain Analysis | | ■ | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| Modular Network Design | | | | | | | | ■ | | ■ | ■ | ▥ | ■ | | | | | | | | |

**Table 4.13: Mapping of BPR tools and techniques on Stage-Activity Framework of Kettinger et al. (1997)**

Two things can be observed. First, the ability of MND to support the determination of external customer requirements by means of the definition of service elements. Most other - similar - tools and techniques, such as data flow diagramming, process flowcharting or IDEF tools, lack this specific ability. Second however, we did not find any concrete support for the fact that MND could support the actual definition of new process concepts. *Carrier* managers claimed this was pure expert knowledge and an experience based effort. MND could only be used to analyze a pre-defined scenario, according to these managers. Therefore the S4A1 cell (Define and analyze new process concepts) has only been shaded for fifty percent. One could, of course, claim that simulation tools or flowcharts neither can support the definition of alternative scenarios. This could be true but the focus of our analysis was not to judge the mapping of Kettinger et al. of other tools and techniques on their framework, but merely to map MND on the framework in an objective manner.

Knowing this we can proceed to the next step, which is determining whether MND was actually a good method to use in both studies. For this purpose, we again use the work of Kettinger et al. (1997). We found, using their BPR Techniques Applicability Guide, the following taxonomy of the two *Carrier* studies:

| Case<br>Characteristic | Distribution | Air Logistics |
|---|---|---|
| **Process structuredness** | High | High |
| **Project radicalness** | Medium | High |
| **Customer focus** | Medium | High |
| **Potential for IT enablement** | High | High |

**Table 4.14: Characteristics of both case studies**

The business processes of both studies were reasonably structured and orderly. While the focus and strength of MND mainly lie in process capture and modeling, process prototyping and process measurement, the use of MND in both projects can be justified.

The radicalness of the Distribution case was lower than that of the Air Logistics case (see table 4.15). In the Distribution case no radical process restructuring seemed necessary, while in the Air Logistics case an entirely new market opportunity for *Carrier*, i.e. door-to-door coordination, needed investigation. Kettinger et al. designed a project radicalness planning worksheet for determining the radicalness of a redesign project. Below this is done for both studies. The D indicates Distribution, A the Air Logistics case.

| Factor | Question | Process Improvement | Process Redesign | Radical Reengineering |
|---|---|---|---|---|
| **Strategic centrality** | Is the targeted process merely tangential (1) or integral to the firm's strategic goals and objectives? | 1 2 | 3 **D** | 4 **A** 5 |
| **Feasibility of IT to change process** | Does IT enable only incidental change (1) or fundamental process change (5)? | 1 2 | 3 | 4 **D** **A** 5 |
| **Process breadth** | Is the scope of the process intra-functional (1) or inter-organizational? | 1 2 | 3 **D** | 4 **A** 5 |
| **Senior management commitment** | Is the senior management visibly removed (1) or actively involved (5) in the BPR efforts? | 1 2 **D** | 3 **A** | 4 5 |
| **Performance measurement criteria** | Are the preferred performance measurement criteria efficiency based (1) or effectiveness based (5)? | 1 2 | 3 **D** **A** | 4 5 |
| **Process functionality** | Is the process functioning marginally (1) or is the process not functioning well at all (5)? | 1 2 | 3 **D** **A** | 4 5 |
| **Project resource availability** | Are only minimal resources (1) available to support the process change or are resources abundant (5)? | 1 2 **D** **A** | 3 | 4 5 |
| **Structural flexibility** | Is the organizational structure rigid (1) or is it flexibly conducive (5) to change and learning? | 1 2 **D** **A** | 3 | 4 5 |
| **Cultural capacity for change** | Does the culture support the status quo (1) or actively seek participatory change (5)? | 1 2 **D** | 3 **A** | 4 5 |
| **Management's willingness to impact people** | Are only modest impacts on people tolerable (1) or is management willing to deal with the consequences of disruptive impacts (5)? | 1 2 | 3 **D** **A** | 4 5 |
| **Value chain target** | Is the BPR effort targeted at an internal support process (1) or a core process (5)? | 1 2 | 3 | 4 **D** **A** 5 |
| **Propensity for Risk** (1: Risk Averse to 5: Risk Taking) | | 1 2 | 3 **D** | 4 **A** 5 |

**Process Change Strategy** = (Avg. Score of Contingency Factors + Risk Propensity) / 2:

- Distribution = (31/11 + 3) / 2 = 2.91
- Air Logistics = (35/11 + 4) / 2 = 3.59

**Table 4.15: Radicalness analysis of both case studies**

Using both measurements of project radicalness, according to Kettinger et al. the focus in the second case should have been more on creative thinking, change management and the definition and design of alternative process structures, instead of diagnosing the current situation. Kettinger proposes brainstorm sessions, collaborative workgroup software or even role playing focused on creative thinking for that purpose. Latter techniques were not applied in the cases (at least, not by the researchers) while they do not belong to an empirical MND application. On the other hand Kettinger et al. do not rule out the use of diagramming or modeling techniques either.

Customer focus was high in both cases, but highest in the second case at Air Logistic. Therefore, customer requirement analysis was most important in the latter case. The definition of service elements is a useful step in such an analysis. In MND, the determination of the customer requirements is in fact an integral part of the diagnostic and redesign stages, not just of the initiation stage.

The final project characteristic concerns the potential for IT enablement. In the cargo industry in general, the potential for IT to change and affect processes is very high. Even more, information is *the* source for competitive (and technological) advantage (Hebert et al. 1998, Radstaak & Ketelaar 1999). Therefore, special attention should be paid to IS systems analysis and design. MND partly does that by the use of seven IT-based guidelines for redesign. However, it turned out that these guidelines were difficult to apply on MND modeling. Therefore, a better operationalization of the guidelines within the model needs to be established to offer better support for projects with high levels of IT enablement.

Summarizing these arguments one may conclude the following concerning the conceptual validity of the empirical descriptive MND.

1. MND is suitable to support the determination of external customer requirements by means of the definition of service elements. In MND, the determination of the customer requirements is an integral part of the diagnostic and redesign stages, not just of the initiation stage. Most other - comparable - tools and techniques, such as data flow diagramming, process flowcharting or IDEF tools, lack this specific ability. We did however, not find any concrete support for the fact that MND could support the actual definition of new process concepts.
2. While the focus and strength of MND mainly lie in process capture and modeling, process prototyping and process measurement, the use of MND in both projects can be justified. Both projects were characterized as structured and orderly.
3. When project radicalness is high, MND may still be useful but should be combined with other tools and techniques such as brainstorm sessions, collaborative workgroup software or even role playing focused on creative thinking.
4. The definition of service elements is a useful step in customer requirements analysis. Better operationalization of the IT-based redesign guidelines required within the model needed to offer better support for projects with high levels of IT enablement

**Robustness**

Robustness is the extent to which the model is usable in situations not expressly defined in the model's development, i.e. the range of applications of the model. Hoogeweegen already states that MND could be used for more than just assessing the impact of EDI. The impact of other emerging technologies, such as the Internet, could be assessed as well. He briefly mentions investigating the contribution of MND to the currently frequently implemented Enterprise Resource Planning software, such as Triton (Baan) or SAP. In our second empirical study, we indeed investigated a scenario where the Internet played a central role (section 4.5.4). It is however questioned whether the *impact* of such technologies should simply be measured by assessing costs and throughput times of order fulfillment. The impact of such technologies may well be more comprehensive, changing customer channel management, storage policies, distribution channels, etc. Although costs and throughput times are very important in the field of logistics, it was found in the case analyses that MND is not a logistics-specific tool. Many crucial issues in logistics (inventory level, capacity planning etc.) are not taken into account.

Therefore, we may conclude that MND is not particularly bound to one specific area of business – it is fact quite robust. In theory, it could just as well be applicable in the car manufacturing industry as in the financial service area. This high robustness is at the same time a significant weakness of the model, causing each application to be very superficial and at times, even unreliable and incomplete. MND supports managers in a very conceptual manner by offering a new perspective on the 'art of doing business'. It helps them in rethinking what they are doing and how they might change their strategy with respect to their customers and value chain partners. Combining this strategic vision with a very detailed operational process assessment however, often leads to confusion and indefiniteness about the precise objectives and range of application of the model. The dual perspective of MND in the Bosman (1986) framework illustrates this strikingly. Improving the model should therefore be done in one of these directions (strategic/visionary vs. operational assessment), not both.

**Experimental validity**

Determining the experimental validity of the model and its applications would mean that we have to check the output of the different scenarios with results that actually occur in the future. Obviously, this cannot be done at the time. No claims can therefore be made about the experimental validity of the model.

**Internal validity**

Internal validity concerns the interpretability of the results of the model. This means, for instance, verifying the relations and variables of the logic and data model. It also involves clarity and reliability of the model and its results. For different reasons (see the case study sections) the results are less reliable than one would desire. Mathematically the model is sound and easily verified, but because the theoretical validity of the logic model especially was insufficient, internal validity becomes a superfluous measurement.

**Operational validity**

For a system to have operational validity, it would have to be of value to the client in tackling the problem situation for which the system was built. A check has to be done whether the system was available to help with decision-taking and whether it was sufficiently understandable for the user to explain the system and its outputs to his/her peers/bosses (Finlay & Wilson 1997). Referring to the work of Mintzberg et al. (1976) the proposition on rational decision making is 'The more extensive the use of analytical techniques, the better the chance a firm has of selecting the optimal strategy.' Considering the fact that each DSS is an analytical technique operational validity should be ensured. However, extensive work has been carried out on the effectiveness of DSSs (e.g., Sharda et al. 1988, Benbasat & Nault 1990) and the question whether a DSS actually leads to better decisions remains to a large extent unanswered and disputed.

With respect to MND operational validity is hard to determine. First, because the method has not been installed or implemented within an organization. Second, MND tries to offer support for a value chain of organizations. It could therefore happen that one organization is more supported with the analysis than another. Consensus is hard to achieve, especially in a very competitive environment such as the air cargo industry. The nature of the interorganizational situation may therefore preclude the use and implementation of the results of the model. In the two cases carried out, the reactions of the *Carrier* managers involved were positive; they stated that MND increased insight in their own business processes and in those of their chain partners. On the other hand however, in neither of the cases the alternative scenarios were implemented. They were satisfied with the outline of possible scenarios, but were not convinced that all aspects of these scenarios were taken into account sufficiently (such as chance of process errors, consequences of tracking & tracing, etc.). Moreover, both the internal situation at *Carrier* (a reorganization was at hand) and external, political factors prevented implementation of the scenarios. Concluding, we may say that the operational validity of MND can never be higher than the validity of the logic and data model. Both validity types need to be sufficient, otherwise operational validity will never be sufficient as well.

### 4.6.4 Interface and face validity

The MND-based DSS – *Erasmus in Chains* – was programmed in Microsoft Access, using Visual Basic tools. The process module networks output was generated with Microsoft Project, which contained the PERT chart functionality. The use of Microsoft products guaranteed a well-known and proven to be successful user interface. Furthermore, the basic structure of MND, depicted in figure 3.2 of section 3.3.3, with the four modeling steps, was copied into the program. Definition of all elements, the linking of the elements and the definition of alternative scenarios all was done according to this structure. This proved to be a very easy-to-use structure. The usability of the system was therefore sufficient. Literature (e.g., Bidgoli 1989, Eberts 1994) on DSS in general and the human-computer interface particularly, further confirms the advantage of using well-known programs and interfaces to make the user at ease with the program and increase the usability of it. Bidgoli (1989) mentions five criteria worthy for consideration in interfaces: simplicity, consistency, familiarity with user's world, informativeness and flexibility. All factors are adequately taken care of in Erasmus in Chains. Information validity finally, refers to the way the information, present in the system, is presented to the user and how easy it is to retrieve it from the system. The argument for sufficient validity is here that the user itself is mainly responsible for data entry into the system and that the same interface is used to retrieve the data back from the system.

Face validity is a somewhat superficial measure of the similarity of aspects of the system or model with information from other 'approved' sources. In other words the question needs to be answered whether the model 'feels' or 'looks' good. This question can be answered affirmatively. *Carrier* managers confirmed the added value of and vision behind MND in two ways. First, it could help them in getting a better overview of their costs. In other words MND as an accounting system. Second, they liked the conceptual prescriptive part of the model. They were quite positive about it and saw many of the underlying trends and developments, such as mass-customization, quick response logistics and make-to-order strategies, occurring in their own business practice. The conceptual prescriptive part of MND is topic of discussion in the next section (4.7).

### 4.6.5 Summary of validity of empirical descriptive MND

Previous arguments are summarized by means of the validation framework introduced in section 3.5.2.

<table>
<tr><th colspan="2">Validity variables</th><th>Validity</th></tr>
<tr><td rowspan="2">Logical validity</td><td>Analytical validity</td><td>Flexibility: Sufficient<br>Divided in agility and versatility. Based on well-established literature sources.<br>Throughput times: High<br>The question however, whether throughput time should be included at all in the model (analytical validity) is undisputed, especially in the air cargo sector. Throughput and delivery times are essential in this time-critical industry.<br>Assessing costs: High<br>The appropriateness of assessing costs on supply chain level is undisputed. Especially in the air cargo sector, where competition is mainly based on price-setting and cost-level this functionality is a high priority requirement for an assessment model.<br>Logic for linking elements: High<br>The usefulness and necessity of such a linking architecture is apparent. Such an architecture could not only make the modeling effort easier and more straightforward, it could also improve the conceptual prescriptive MND.</td></tr>
<tr><td>Theoretical validity</td><td>Flexibility: Low<br>Operationalization theoretically invalid: Agility ‘simply’ expressed as throughput time is inadequate (e.g., Goldman, Nagel & Preiss 1995). The operationalization of versatility is also inadequate. MND is, in the current version, not able to adequately assess the degree of flexibility of a value chain.<br>Throughput times: Sufficient<br>Determination of critical time of a deterministic flow is appropriate and theoretically sound, just as the calculation of total time by accumulating all individual activity durations. Assessment of critical and throughput time in a deterministic manner has however a very low operational validity in the air cargo industry (and most likely in other industries as well).<br>Costs: Sufficient<br>Determination of costs on supply chain level difficult: costs vs. tariffs. Clear perspective needed.<br>MND only uses four ABC building blocks; the ‘activity driver’ misses. Activity driver is a factor used to assign costs from an activity to a cost object.<br>Logic for linking elements: Low<br>No satisfactory formal logic or architecture was available to determine the relationships between the MND modeling elements (mapping of service elements on production elements, sequencing the process modules etc.). For instance, translation of service elements into production elements is not possible for all types of service elements and their specific relations with production elements.</td></tr>
</table>

| | | |
|---|---|---|
| **Data validity** | Accuracy<br><br>Precision<br><br>Theoretical validity | **Low:**<br>• Bottom-up focus of the model requires the estimation of single-order related costs. In practice this is often hard to accomplish, causing each activity-based cost estimation to be less accurate and precise. Only when organizations keep full and detailed account of their costs will the modeling effort be more reliable.<br>• No distinction made in the data model between resources that 'disappear' after use and thus need to be replenished and ones that are only temporarily unusable but will become available again after some time.<br>• MND could be benefited by more detailed guidelines and definitions about the required level of detail for the process modules in relation with the objective of the application. |
| **General validity** | Conceptual validity | **Sufficient:**<br>• MND suitable to support determination of external customer requirements. Added value compared to other tools and techniques, such as data flow diagramming, process flowcharting or IDEF tools.<br>• MND especially useful in structured and orderly projects.<br>• When project radicalness is high, MND may still be useful but should be combined with other tools and techniques such as brainstorm sessions, collaborative workgroup software or even role playing focused on creative thinking.<br>• Better operationalization of the IT-based redesign guidelines required to offer better support for projects with high levels of IT enablement. |
| | Robustness | **Sufficient**: In theory, MND could just as well be applicable in the car manufacturing industry as in the financial service area. This high robustness is at the same time a significant weakness of the model, causing each application to be very superficial and at times, even unreliable and incomplete. |
| | Internal validity | **Low**: results are less reliable than one would desire; theoretical validity of logic model was insufficient, therefore internal validity becomes a superfluous measurement. |
| | Operational validity | **Low**: scenarios were not implemented; operational validity is limited by validity of logic and data model |
| | Experiment al validity | Not determined |
| **Interface val.** | Theoretical validity | **Sufficient**: simplicity, consistency, familiarity with user's world, informativeness and flexibility are sufficient. |
| | Usability | **Sufficient**: well-known software is used |
| | Information validity | **Sufficient**: user itself is responsible for data entry into the system; same interface is used to retrieve data from the system |
| | Face validity | **High**: added value and vision behind MND approved by *Carrier* managers |

**Table 4.16: Summary of validity of Empirical Descriptive MND**

## *4.7 Conclusions: Validating the Conceptual Prescriptive MND*

According to the conceptual prescriptive part of MND, four constructs should lead to flexible, cost-efficient customized value chains. In the following sections, we will discuss the validity of each of the constructs of the conceptual prescriptive MND. First, the appropriateness of the construct is discussed. This means that we want to determine whether the constructs are already applied and operationalized by the stakeholders. Second, we want to find an answer to the question whether the constructs can be translated into empirically useful guidelines and methods. Assessment of the validity of the constructs is thus based on the arrow from cell 1 to 3 in the Bosman framework (figure 3.4) that states that every conceptual prescriptive theory must be translatable into an empirical model or theory. In section 3.5.2 it was already explained exactly how this validation would be done; we follow described procedure.

### 4.7.1 Presence of a central chain coordinator

It was mentioned that the bottom-up, order-fulfillment-based perspective of MND is inadequate to assess the role of the coordinator with respect to value chain flexibility. No reliable judgements can be made with the model about which organization should coordinate or whether there should be a coordinator at all. Assessment of different coordination mechanisms and structures (Malone & Crowston 1994) and the role of broker/architect discussed (Miles & Snow 1986) should be included in the model to actually make the link between this construct and value chain flexibility. This would however largely impact the character and purpose of the model. This conclusion was drawn from the case study finding that chain coordination consists of far more than just order fulfillment. The only way we could support the coordinator was by carrying out an ex ante analysis of different sub-contractors.

Besides this inadequate operationalization of the construct in the empirical model, what can we say about the appropriateness of the construct in the air cargo setting? Providing a one-stop fully customized logistics service to shippers becomes increasingly important in the cargo world. Organizations are competing with each other to fulfill this role for their customers. They try to increase their network of partners by entering close partnerships and alliances to ensure door-to-door delivery within very strict time limits. Global Supply Chain Management, Quick Response Logistics and Value Chain Integration are only a few of the trends going on this industry. Radstaak & Ketelaar (1999) extensively describe these trends, illustrated with many case studies. In line with these trends and developments, the appropriateness of chain coordination as value-added competence is certainly true.

In the air cargo industry, coordinating the chain has to do with setting up good contracts with potential partners and maintaining good relationships with them. It involves designing and governing efficient and cost-effective transportation networks and dealing with many juridical and financial affairs, such as responsibilities for the freight, customs restrictions and conditions. The MND construct 'central chain coordinator' does not elaborate on all of these tasks, i.e. no empirical guidelines are available that may be useful to the stakeholder. The construct just argues that a chain may be benefited by a central chain coordinator. In this respect, the possibility to translate the construct into empirically useful guidelines needs further elaboration.

In fact, what we want to know, is whether the presence of a central chain coordinator is always recommendable to improve chain performance? Can we resolve, based on our findings in the case studies, which factors determine the appropriateness and feasibility of a central chain coordinator and thus supply the construct with better founded empirical guidelines for implementation?

The first and most important factor found was the need of the customer of the (logistics) chain for (worldwide) one-stop shopping. Nowadays, many multinational companies are pushing for single entities managing their entire logistics processes (Radstaak & Ketelaar 1999). Centralization of control and coordination of the chain seems the most obvious way to achieve this one-stop-shopping structure. Second, central coordination could increase visibility and reliability of the chain and enable easier and cheaper linkage of IT systems (such as ERP). Third, central coordination could enable 'seamless supply chains', by reducing lead times and transportation costs. Most likely however, trust and power among the chain partners are conditional factors that need to considered. Only an organization with enough power and trust can establish itself in such a central position within the chain. Furthermore, the chain needs to be transparent and information systems need to be present that contain all information required about (possible) supply chain partners to make the right selection decisions and to monitor and control the chain. If one of these factors is insufficient then the other stakeholders in the chain probably will not allow this organization to fulfill this - profitable - position.

### 4.7.2 Temporary alignments of organizations

Empirical findings in the air cargo sector showed just the opposite of dynamic networking and temporary alignments of organizations. These findings include the ongoing efforts of transport organizations to merge with, ally with or take over other organizations, as described in specialist literature such as *Nieuwsblad Transport* or Internet-sources such as www.cargoweb.nl.

As we noted earlier in section 4.5.3, *Carrier*'s flexibility merely is achieved by its ability to deal with errors or mistakes during the process or other exceptions that would occur compared to regular business. To do so they try to make as many agreements and contracts with external parties as possible. In this respect they prefer static planning and close relationships and alliances with other organizations. Flexibility is merely accomplished within these fixed partnerships, not by dynamically switching between partners or sub-contractors. They claim that their shippers also profit most from this type of static planning. When *Carrier* knows the production and manufacturing forecast of its shippers, it is able to plan its shipments way ahead, thus saving costs for both parties involved. This in fact contradicts the notion that temporary interorganizational alignments prevail with respect to cost efficient flexibility.

Furthermore, the use of dedicated, non-compatible, information systems for booking, tracking & tracing, invoicing etc. further confirmed this. Therefore, empirical translation of the construct proved hard to do. No evidence could be found of the contribution of this construct. Nevertheless, the operationalization of this construct in MND proved appropriate. By placing the customer order as starting point of the order fulfillment process, one can actually consider each order a temporary alignment of organizations, i.e. temporary for the duration of this specific order. The external validity of the model (to what extent does the model represent the real situation?) is however very low in this case, just as the prescriptive value: the claim that temporary alignments should be preferred cannot be validated.

### 4.7.3 Direct translation of customer requirements into production

This construct proved to be a very appropriate and theoretically sound construct. Leaving aside the difficulties of operationalizing the exact mapping procedures, the concept was very applicable. Proofs of this were the VALUE tool development of *Carrier* and the capability sheets of *Carrier*. This way of customer-focused organizing is used by *Carrier* to control its cost level in relation to provided services to their customers. Theoretical justification can be found in marketing literature on mass-customization, mass-individualization, one-to-one marketing etc. In fact, this construct is very closely related to the construct of modularity as is often mentioned in the scientific literature. Modularity is, together with ICT, viewed as *the* enabler for mass-customization. Therefore, elaboration on the construct of directly translating customer requirements into production will be done in the next section on modularity.

### 4.7.4 Modularity

The question is whether the concept of modularity as used in MND is theoretically sound and appropriate. And next, if so, whether the modularity construct can be translated into empirically useful guidelines. The first question will be elaborated on first. The exact way modularity is incorporated in MND is a little ambiguous. Obviously the process modules refer to modularity of processes, i.e. decomposing entire processes into modular activities. Hoogeweegen refers in his definition of a process module, among others, to Pine et al. (1993) and McCutcheon et al. (1994). They themselves refer to modularity of products and services. This type of modularity can be found in the service elements. Next to these two types of modularity, products/services and processes, Hoogeweegen also states that within MND organizations are viewed as modular entities (Hoogeweegen 1997:64). These organizations participate in temporary supply chains to fulfil customer orders. Although Hoogeweegen does not further elaborate on this notion, this is in fact a third level of modularity: modularity of supply chains. Fine (1998) also distinguishes between these three types of modularity.

Summarizing, we see that the (prescriptive) construct modularity has thus been translated, within MND, into three empirical guidelines: modularize products, modularize processes and modularize supply chains. According to the conceptual prescriptive MND, implementing these guidelines should lead to more supply chain flexibility and enable customization of products and/or services. Whether these guidelines are indeed useful remains however an unanswered question.

The first reason for this is that MND requires a better operationalized definition of modularity. Modularity is a design feature in the sense that a design can be highly modular or little modular; it is no binary measure. In the case of little modularity, one often speaks of an integral design. Such a distinction between modular and integral - or intermediate forms - is lacking in MND. Statements about the desirability of a construct or concept are only useful when the construct itself allows for some variability in value. Second, when such an operational definition would be added, no contingent factors are discussed that could limit or strengthen the effect of using modularity for designing products, processes and supply chains. It may be true that some products, processes or supply chains are not benefited at all by using modularity, but instead would gain more from an integral design. In other words the modularity construct requires more elaboration and investigation before one may conclude that modularity - sec - leads to more supply chain flexibility and customization. This will therefore be the topic of the next research module (chapters 5,6 and 7).

### 4.7.5 Cost-efficient customized value chains

Finally, to what extent can the dependent variable of the conceptual prescriptive MND be translated into empirically useful guidelines and methods? Does the use of the previously discussed concepts, such as modularity and temporary alignments of organizations, indeed enable cost-efficient customized value chains or business networks? Based on our findings we can state the following. It was found that the construct 'temporary alignments' and 'central coordinator' are very closely related to each other; they can not be treated separately. Both constructs deal with the way organizations interact with each other, make up contracts, share information and so on. It may be claimed that temporary alignments of organizations can only work with a dedicated coordination structure, i.e. a structure that *enables* temporary alignments of organizations. In other words temporary alignments of organizations require some sort of broker or coordinator who initiates the network, selects the participants in the temporary cooperation and divides responsibilities. This can be an organization, but might as well be a software program or another entity. The same more or less holds for the constructs modularity and direct translation of requirements into production. Use of modular products and processes *enables* direct translation of customer requirements into production.

### 4.7.6 Summary

Just as in section 4.6 we use the MND validation framework (table 3.6) to summarize our findings.

| Validity variables | | Validity |
|---|---|---|
| **Independent variables** | **Coordination structure** | Bottom-up, order-fulfillment-based perspective of MND inadequate to assess the role of the coordinator<br>Chain coordination as value-added competence appropriate: centralization of control and coordination of the chain seems the most obvious way to achieve one-stop-shopping structure.<br>The possibility to translate the construct into empirically useful guidelines needs further elaboration.<br>Central coordination could increase visibility and reliability of the chain and enable easier and cheaper linkage of IT systems. |
| | **Temporary alignments** | Empirical findings in the air cargo sector showed just the opposite of dynamic networking and temporary alignments of organizations.<br>Flexibility is merely accomplished within these fixed partnerships, not by dynamically switching between partners or sub-contractors.<br>Use of dedicated, non-compatible, information systems for booking, tracking & tracing, invoicing etc. further confirmed this.<br>Operationalization of this construct in MND proved appropriate.<br>The external validity of the model very low in this case, just as the prescriptive value: the claim that temporary alignments should be preferred cannot be validated. |
| | **Requirements into Production** | This construct proved to be a very appropriate and theoretically sound construct. Leaving aside the difficulties of operationalizing the exact mapping procedures, the concept was very applicable. |
| | **Modularity** | The exact way modularity is incorporated in MND is a little ambiguous.<br>MND requires a better operationalized definition of modularity.<br>No contingent factors are discussed that could limit or strengthen the effect of using modularity for designing products, processes and supply chains. |

| | | |
|---|---|---|
| **Dependent variable** | **Cost efficient customized supply chains** | Temporary alignments of organizations can enable cost-efficient customized supply chains only when a dedicated coordination (or governance) structure is in place, i.e. a structure that enables temporary alignments of organizations.<br>Use of modular products and processes enables direct translation of customer requirements into production, which subsequently can enable cost-efficient customized supply chains. |

**Table 4.17: Summary of validity of Conceptual Prescriptive MND**

Based on these findings, we propose that the conceptual prescriptive MND, which indicates the relation between the four constructs and cost-efficient customized value chains, should be changed. The new conceptual prescriptive MND model now looks as follows:


**Figure 4.15: New conceptual prescriptive MND**

The new model indicates that temporary alignments could indeed enable cost efficient customized value chains, but that the chosen coordination structure is essential. Furthermore, the use of modularity may enable direct translation of customer requirements into production, which could subsequently be conducive to cost efficient customized value chains. By no means is this model a complete (prescriptive) model of how value chains could become cost efficient and customized; it only stresses four important factors that should be considered.

## *4.8 Discussion and directions for further research*

### 4.8.1 Application areas of MND

Overviewing the last two sections, we may conclude that MND definitely has its merits but that several aspects – both conceptual as descriptive - of the approach definitely need further improvement. One of the main conclusions of the validation effort was the finding that MND currently is very generically defined. This low specificity should allow the approach to be useful in many different industries (cargo, automotive, apparel etc.) for investigating many different business scenarios (from the impact of ICT to the improvement of logistic operations). However, MND supports managers only in a very conceptual manner by offering a new perspective on the 'art of doing business'. It helps them in rethinking what they are doing and how they might change their strategy with respect to their customers and value chain partners. Unfortunately, combining this strategic vision with a very detailed operational process assessment often leads to confusion and indefiniteness about the precise objectives and range of application of the model. Future use of MND is benefited by a clear overview of application areas, case objectives and project types where application of MND may be useful. Based on our findings in the case studies, we come up with the following criteria for useful applications of MND.

**MND - Empirical Descriptive**
- Focus on requirements of end-customer
- Focus on process *flow*: cost and throughput time of order fulfillment
- Structured processes
- Sufficient data availability
- Analyze consequences of incremental redesign scenarios

**MND - Conceptual Prescriptive**
- Awareness creation
- Scenario analysis (non-quantitative)
- ICT as enabler for scenarios

The focus of an application of MND within a business network (or a single organization) should always be on the requirements of the end-customer. Without such a focus, application of MND is useless, even impossible. The use of service elements calls for such a focus. Furthermore, the focus of an assessment with MND should be on the primary process *flow*, i.e. the activities to be carried out to fulfill a particular order just as in, e.g., Process Flowcharting. Within such an analysis one cannot include the analysis of supporting activities such as human resource or technology management. Next, these processes should already be quite structured. MND requires such a structure because of its one-directional, sequential way of modeling processes. MND cannot handle complex loops, if/then situations or other process complexities. MND cannot handle stochastic throughput times either. Another important requisite for carrying out an MND analysis is the availability of - often detailed - process data. Finally, because of this structuredness and the need for detailed process data, one cannot analyze very radical alternative process handling scenarios with MND. Only small, incremental redesign scenarios can be assessed, to ensure sufficient reliability and general validity of the model and its application.

With respect to the conceptual prescriptive MND one may argue that its mere use is for creating awareness amongst managers and other practitioners about how they could organize their business, different from what they are doing now. The concepts of modularity, temporary alignments and the direct translation of customer requirements into 'satisfiers' may shed new light on the 'art of doing business'. It may support managers in thinking of new scenarios for their organization and discover opportunities for the use of ICT in their own environment focused on satisfying the needs of their customers, instead of simply cutting costs or automate processes. Techniques such as brainstorm sessions, collaborative workgroup software or role playing focused on creative thinking may further support such an application of MND.

### 4.8.2 Research directions for the empirical descriptive MND

At the end of this research module, we may define several directions for further research on MND and related topics. Improving the model should however be focused on one MND perspective in particular (conceptual prescriptive or empirical descriptive), not both. For each perspective, we summarize a number of issues that require further attention or otherwise may be worth investigating. For some of these issues we already present a more worked out beginning, on which future research can build. In effect, these directions serve as the start of a new empirical cycle of research. The analysis described in this chapter showed that validity of the logic model and general validity (esp. operational validity) were inadequate. This section provides a number of specific directions in which the empirical descriptive MND may be improved.

**1. Assessing mass-customization strategies**

The first finding relates to investigating mass-customization strategies. For this purpose, one should at least be able to investigate the implications of different, customized orders in an effort to achieve economies of scale (see figure 4.1). In addition, investigation of economies of scope should be possible as well. The following figure illustrates the basics of such an approach.

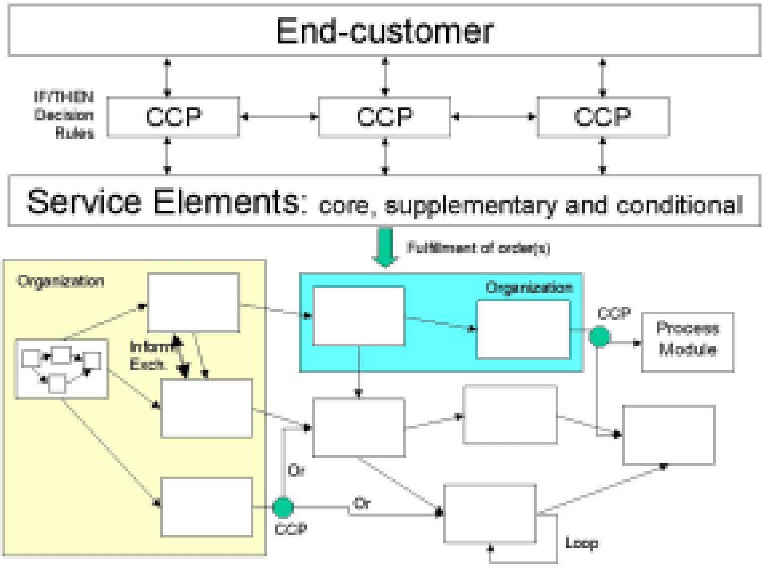



**Figure 4.16: Mass-Customization dynamic simulation approach**

This new (simulation) approach solves a number of shortcomings MND possessed, while it also introduces some new functionalities, such as chain dynamics and evaluation of customer contact. The features of the approach are summarized below.

- CCP is the *customer contact point*. This could, e.g., be a web-site, a customer service center or an ordinary counter. CCP's can also be software agents. They do possess certain intelligence (modeled as IF/THEN decision rules), on which they base the initial order fulfillment path through the network. They do not function as central coordinators while the process modules are partly autonomous and take their own decisions. They mainly function as the facilitator of the customer interface and determine what to do next.

- Supplementary service elements can become core service elements when customers have asked for them quite regularly (see Kotha 1995). Or vice versa: core services can become more supplementary. For instance, the height of a car cannot be changed nowadays, but maybe a customer would like to do that.
- The process module network this time is initially fixed, orders run through it – the exact way on order runs through the network depends on the customer's requirements or organizational feasibility to process the order. Order paths can also change because at some moment the customer changes its requirement, only knows the exact requirement at that moment, for instance, due to earlier events or the resources required are unavailable. When the algorithm detects such a resource conflict (e.g., two orders want to make use of the same resource, which is only available for one order), it searches for ways to avoid the delay by constructing another process module network, which would not be in conflict with other orders. This might, for instance, mean another selection of sub-contractors.
- The process modules no longer are just activities; they are now autonomous and adaptive, being either people, business units or entire organizations. Process modules further possess certain performance indicators that could improve over time and are measured over time as well. The CCPs need to know these performances. If they do not, certain process modules may take over their role over time because the customers are very satisfied with their performance in contrast with the performance of the CCP (disintermediation).
- Performance can still be based on the degree of flexibility of the network. The dynamic way of modeling allows better operationalization of the agility and versatility concepts.

**2. Assessment of supply chain costing**

A very important problem that occurred was the measurement of supply chain costing (SCC), instead of pure, intra-organizational activity based costing. The SCC approach employs the same techniques used by activity based costing in assigning resource costs to activities. The difference between SCC and ABC occurs when activities span firms or when costing other firms' activities. In the cargo industry, and in many others as well, organizations work with however tariffs for which they hire each other's services and charge their own customers. An approach can be developed that deals better with this apparent difference and explicitly focuses on the measurement of supply chain costing.

**3. Focus on guidelines for ICT leverage and assessment of ICT investments**

It turned out that the seven generic IT-based guidelines for redesign were difficult to apply within the MND model (see section 4.4.4). Therefore, an improved model may be developed, which specifically focuses on ICT redesign guidelines and subsequently will thus be able to assess the business impact of ICT investments, related to these guidelines. This would, for instance, mean that the content of the information exchanged via these technologies should be included in the model as well, to enable comparison of different ICT scenarios. Furthermore, when we take Davenport & Short's (1990) IT capabilities – see section 3.4.3 - as starting point, the following modeling perspectives become apparent:

- Transaction costs
- Throughput times

- Division of labor; role and task integration
- Outcome flexibility and quality
- Process control
- Structuredness of information
- Decision logic
- Process analysis
- (Inter)-Organizational structure

Most likely, it will be impossible to design a model that incorporates all of these perspectives. IDEF is a good example of an approach that consists of different complementary parts, which together may provide insight in all the previously mentioned perspectives relevant for IT assessment. Our suggestion would be to choose a perspective in line with the type of IT application that is to be assessed. For instance, assessing EDI requires a perspective focused on interorganizational structures, transaction costs, throughput times and the structuredness of information. The impact of expert systems may be assessed from a process analysis and decision logic perspective (does the use of an expert system improve analysis and decision processes?). We expect that in most of these cases no new models need to be developed. Instead, one could rely on the vast library of existing tools and methods, well described by Kettinger et al. (1997) and select the appropriate ones suitable for the objective at hand.

### 4.8.3 Research directions for the conceptual prescriptive MND

The conceptual prescriptive MND may be benefited by several future research efforts in different directions. The first is the area focused on temporary alignments of organizations (the so called dynamic networks or virtual organizations) in combination with the required coordination (or governance) structure of these networks and the use of ICT. Such a research effort would fit well in the discussion initiated by Malone et al. (1987) on the impact of ICT on the governance of organizations and more recent work on virtual organizations and e-commerce (e.g., Venkatraman & Henderson 1998 provide a nice overview of the current status of this research area).

The other direction would be focused on the use of modularity for customizing products and services. The proposition is that by modularizing products and processes one can achieve high flexibility and customization by constantly changing the way modules interact and by selecting only those modules, which are required by the end-customers. The concept of modularity however needs further investigation, such as better operationalization and analysis of drawbacks, before we can make well-founded statements about the (dis-)advantages of modularity. This includes investigating different types of modularity (products, processes and supply chains; just as Hoogeweegen did). Questions that may be answered are the following. Under what conditions and circumstances is it profitable and worthwhile modularizing products, processes and supply chains? Do organizations that want to follow a mass-customization strategy, not only need to modularize their products and services, but also modularize their business processes and surrounding network of suppliers? This is, in our opinion, the most interesting aspect to investigate further. This will therefore be the central topic of the next dissertation module.

# RESEARCH MODULE 3:

# BUSINESS MODULARITY IN THREE DIMENSIONS

## CHAPTER 5 THEORETICAL FRAMEWORK ON BUSINESS MODULARITY

### *5.1 Introduction*

#### 5.1.1 Research objectives

This third research module of this dissertation investigates the different aspects and opportunities of modularity in relation to interorganizational business network performance in general and effective mass-customization in particular. The justification for carrying out more research on the use of modularity within business networks, largely originates from the research done by Hoogeweegen (1997), who developed a process modeling approach called Modular Network Design. In the previous research module of this dissertation, development, application and validation of the approach was described. This, among other things, led to the conclusion that the approach - and especially its theoretical foundation - could be benefited by a more profound analysis of the possibilities and limitations of modularity for designing interorganizational business networks in order to achieve increased flexibility, innovativeness or responsiveness, for instance, by mass-customizing their products and services.

The first objective of this dissertation module will be to arrive at a clear and useful definition of modularity. We will see in the next paragraphs of this chapter that modularity is a widely used concept, often however, the precise meaning of the concept and its implications are not very clearly specified[13]. Furthermore, in most studies operationalization and concrete performance indication of the use of modularity with respect to 'success' (flexibility, customization, customer satisfaction, innovation rate etc.) is lacking. It remains unclear why, when and to what degree (networks of) organizations should modularize to maximize their performance or why some organizations or business networks are more modular than others. The disadvantages of modularity deserve more attention as well, or as Baldwin & Clark (1997) state: 'If modularity brings so many advantages, why aren't all products (and processes) fully modular?' This issue concerning the positive and negative consequences of using modularity will be the second objective of this research module. The third objective concerns the role of ICT in supporting and enabling a modular design. To what extent can ICT be supportive to a modular system (such as a product, an organization or a business network) and subsequently, increase its effectiveness?

[13] During the realization of this thesis several authors noticed this deficiency as well and several articles and books were published on modularity. They include: Baldwin & Clark (2000), Schilling (2000), O'Grady (2000) and Worren et al. (2000). We have tried to include these recent publications as much as possible, although actually most of them appeared after or during our empirical research.

### 5.1.2 Research questions

Based on previous reasoning, the central research question of this dissertation module is formulated as follows:

**How can modularity enhance the performance of business networks?**

Subsequently, this research question can be divided in a number of sub-questions:

**What is modularity and what different types of modularity exist ?**
**How can we determine the degree of modularity of a system, such as a product, an organization or a business network?**
**When should modularity be applied in an (inter-)organizational setting?**
**How should modularity be applied in an (inter-)organizational setting?**
**Why should modularity be applied in an (inter-)organizational setting?**
**How can the use of ICT support or enable the use of modularity?**

These sub-questions address a number of issues. First, we need to define modularity and find a way to determine the degree of modularity of a system. Second, we wonder why some systems are more modular than others and subsequently why some of these systems should perhaps become more modular (or not). Third, we specifically focus on business modularity, i.e., modularity used for business purposes and ask ourselves when, how and why this type of modularity is or should be applied. Finally, we focus on ICT as an enabler for modularity.

### 5.1.3 Structure

Answering these questions will be done in three stages, all described in this research module. The first stage is carried out on the basis of an extensive literature review, described in this chapter. The next two chapters – 6 and 7 - contain the empirical research carried out to further explore and validate our research framework on modularity. Chapter 6 contains the first exploration of the validity of our research framework, which will be adapted – if necessary – on the basis of our findings in the case. The case study was carried out in the Dutch housing industry. The subsequent chapter, Chapter 7, describes a more statistically sound validation of the research framework by means of a business survey among approximately 200 mass-customizing firms.

This chapter is structured as follows. Section 5.2 contains a discussion of modularity in general, so not specifically used in a business environment. In the next section (5.3) three-dimensional business modularity is introduced. This means, using modularity for product, process, as well as supply chain (or network) design. The subsequent section (5.4) further discusses a number of contingent factors that may influence the effectiveness of a modularity-strategy. Section 5.5 then elaborates on the *pros and cons* of using modularity; for what purposes can modularity be used and what can be gained by it – or not. Finally, we introduce our research framework, or conceptual model, which contains the proposed relationships between the previously introduced constructs. The framework may be used to describe and explain effective modularity strategies or to answer Baldwin & Clark's (1997) question explicated at the end of page 99 of this dissertation.

## *5.2 Modularity in General*

### 5.2.1 Nearly decomposable and loosely coupled systems

We start our discussion on modularity with the concepts of nearly decomposable (Simon 1962) and loosely coupled systems (Weick 1976, Orton & Weick 1990). A complex system – for instance, a product design, an organization structure or a biological system – consists of parts that interact and are interdependent to some degree (Sanchez & Mahoney 1996). Simon (1962) argues that *hierarchy* is an organizing principle of complex systems, which are essentially composed of interrelated subsystems that in turn have their own subsystems and so on. Simon further defines a *nearly decomposable system* as one in which interactions among subsystems are weak (but not necessarily negligible). The interactions between the divisions of a multidivisional organization are representatives of a nearly decomposable system (Williamson 1975, Sanchez & Mahoney 1996). A dynamic network as defined by Miles & Snow (1986) is another example. The tasks within a multidivisional firm or dynamic network of organizations are intentionally designed to require low levels of coordination so that they can be carried out by an organizational structure of quasi-independent entities functioning as a loosely coupled system (Weick 1976).

The concept of organizations as loosely coupled systems is widely used and diversely understood, according to Orton & Weick (1990). Loose coupling is evident when elements affect each other "suddenly (rather than continuously), occasionally (rather than constantly), negligibly (rather than significantly), indirectly (rather than directly) and eventually (rather than immediately)" (Weick 1982: 380). Fourteen years after the founding article of Weick (1976), Orton & Weick (1990) review the empirical and theoretical work by others on loosely coupled systems. They express their disappointment about this work by noting that the original concept was in fact interpreted too simple by fellow researchers. These researchers used an unidimensional interpretation of loose coupling by treating systems as either loosely or tightly coupled. Orton & Weick (1990) however, claim that the original dialectical interpretation should be followed which states that loosely coupled systems consist of responsive elements, which retain evidence of separateness and identity. Table 5.1 below displays the other ways of system interdependencies.

| | | Responsiveness | |
|---|---|---|---|
| | | **No** | **Yes** |
| **Distinctiveness** | **No** | Non-coupled | Tight |
| | **Yes** | Decoupled | Loose |

**Table 5.1: Four types of system interdependencies (Orton & Weick 1990)**

According to Orton & Weick (1990) modularity can be considered as a direct effect of loose coupling, i.e. when elements are both distinct and responsive. As the tightness of couplings increases, i.e. the distinctiveness of the elements decreases, the modularity of the system decreases as well (Orton & Weick 1990). Henderson & Clark (1990) use this in their definition of a module: a physically distinct portion of the product that embodies a core design concept and performs a well-defined function. Modular design avoids creating strong interdependencies among specific component designs and instead tries to create ‘loosely coupled’ component designs. Sanchez & Mahoney (1996) further elaborate on this and define modularity as “a special form of design which intentionally creates a high degree of independence or a loose-coupling between component designs by standardizing component interface specifications”.

We thus observe that the notions of modularity and loose-coupling are closely intertwined and even interchanged sometimes. While Orton & Weick argue that modularity is an effect of loose-coupling, both Henderson & Clark and Sanchez & Mahoney claim that modularity in itself creates loose coupling between components. We tend to agree with the latter, because we believe that it is a modular design that creates component interactions such as “suddenly, occasionally, negligibly, indirectly and eventually” as described by Weick (1982) and not the other way round. Therefore, from now on we consider loose coupling between components to be an important feature of a modular design.

### 5.2.2 Modular systems

Ulrich & Eppinger (1995) argue that modularity is not a dichotomous variable in that most systems can be classified along a continuum from highly modular to highly integrated. This means that the opposite of modular is integral, where all possible intermediate forms can exist as well. We further elaborate on modular vs. integral systems, this time focusing on the work of Schilling (2000). Almost all systems are, to some degree, modular according to Schilling. Many systems migrate towards modularity. Schilling tries to find answers why and when these systems migrate to modularity. She investigates the drives between this move towards either modularity or integrality of systems. For this reason she develops a general systems model which tries to explain why certain systems are more modular than others. A specific form of the general systems model is the inter-firm product modularity model. For the latter model she uses research on organizational modularity and product bundling. We will discuss the general systems model in this paragraph as she gives a good summary of earlier work on the concept and adds useful insights herself.

Schilling argues that modularity at its most abstract level refers to the degree to which a system's components may be separated and recombined. The primary action of increasing modularity is to enable heterogeneous configurations. It increases the flexibility of a system. On the other hand, some systems may evolve towards less modularity. In product systems for example, sets of components that once were easily mixed and matched may sometimes be bundled into a single integrated package that does not allow substitution of other components. Schilling tries to define different factors that explain why a system evolves towards more or less modularity. These factors are summarized as Fitness and Adaptation, Coupling and Recombination, Migration and Equilibria and Overcoming Inertia. We will discuss these factors below and present Schilling's general systems model as well.

**Fitness and Adaptation**

In systems theory a number of assumptions exist. Schilling uses these to explain the perspective of her model. The fitness of the system is the degree to which the system and its context are “mutually acceptable” (Alexander 1964:19) The assumption here is that many complex systems adapt or evolve, shifting in response to changes in their context, or to changes in their underlying components in the pursuit of better fitness. Context creates forces (sometimes conflicting ones) that draw a system toward a particular state. Furthermore, as a system shifts in response to its context, it might also change its context in significant ways. Such a change in context may be the unintentional result of the system's response to its context or the deliberate result of purpose behavior.

**Coupling and Recombination**

Modularity, at its most abstract level, refers simply to the degree to which a system's components can be separated and recombined, according to Schilling. The primary action of increasing modularity is to enable heterogeneous configurations. Basically, all systems are ultimately separable, although much of the functionality and performance may be lost due to the separation. Important is whether a system can be put together again after separation and whether it can function as before. A highly modular system thus allows easy disaggregation and recombination of components. However, even in systems in which recombination is possible, there might be some combinations of particular components that work better together than others. The degree to which a system achieves more functionality through its components being specific to one another can be termed *synergistic specificity* - the combination of components achieves synergy through the specificity of individual components to a particular configuration. High levels of synergistic specificity act as a strong force against the system's shifting towards a more modular design.

The concept of synergistic specificity could be further explained by focusing on bundling, which has close resemblance to synergistic specificity. Bundling is defined as the practice of marketing two or more products and/or services in a single "package" for a special price (Guiltinan 1987). These products normally sell better together than apart. The practice of bundling complementary products further assists companies with price discrimination, allowing them to capture more consumer surplus. Examples are: hotels are offering weekend packages that combine lodging and some meals at special rates, some car wash operators offer a simple car wash or a car wash with a set of cleaning packages and airlines bundle vacation packages combining air travel with car rentals and lodging.

Furthermore, heterogeneity of demand and heterogeneity of inputs are likely to increase a system's modularity. Most likely, both factors reinforce each other, while especially the combination of both factors creates powerful incentives to adopt a modular system.

**Migration and Equilibria**

Systems can migrate toward increasing modularity, becoming decomposed at ever-finer levels, until they again find a balance between the pressure to become modular and functionality gained through synergistic specificity. The balance between the gains achievable through recombination and the gains achievable through specificity determines the pressure for or against the decomposition of a system. This trajectory of systems is bi-directional, migrating toward or away from modularity.

**Overcoming Inertia**

Systems are characterized by inertia. They do not respond immediately and vigorously to every external influence. Whether and to what degree a system responds to changes in its context is influenced by forces in the context that create urgency. For instance, urgency indicates the competitive pressure in an industry, the pace of technological change.

In summary, Schilling maps the factors influencing whether a system migrates toward increasing modularity as shown in figure 5.1:

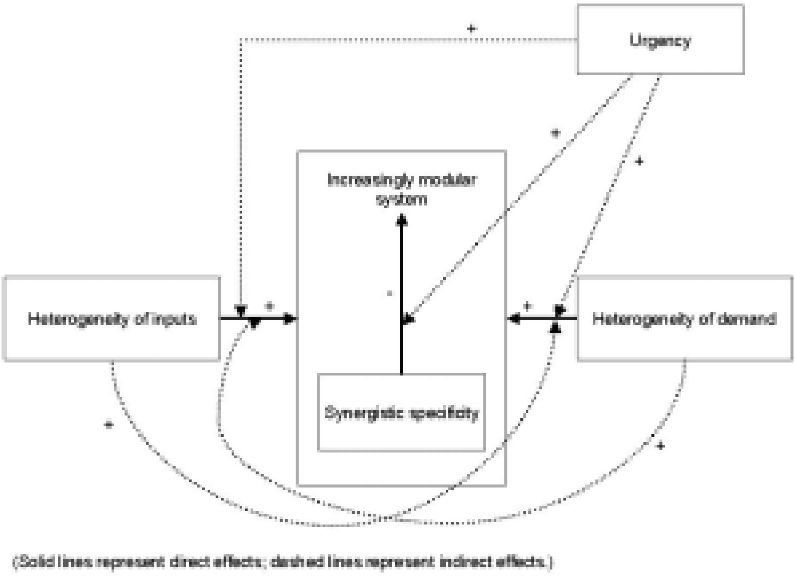



**Figure 5.1: General modular systems theory (Schilling 2000)**

Schilling states that her model may be applicable to various types of systems, such as products, organizations and business networks. This may also include social, biological and technological systems.

### 5.2.3 Modularity in other research areas

As a further illustration of the use (and meaning) of modularity we will take a look at a number of different areas to obtain a better grip of the concept of modularity.

**Modularity in art and mathematics**

Generally, modularity is considered as the use of several basic elements (modules) for constructing a large collection of different possible (modular) structures. In science, the modularity principle is represented by search for basic elements (e.g., elementary particles, prototiles for different geometric structures). The following figure nicely illustrates such a prototile, constructed by Escher.

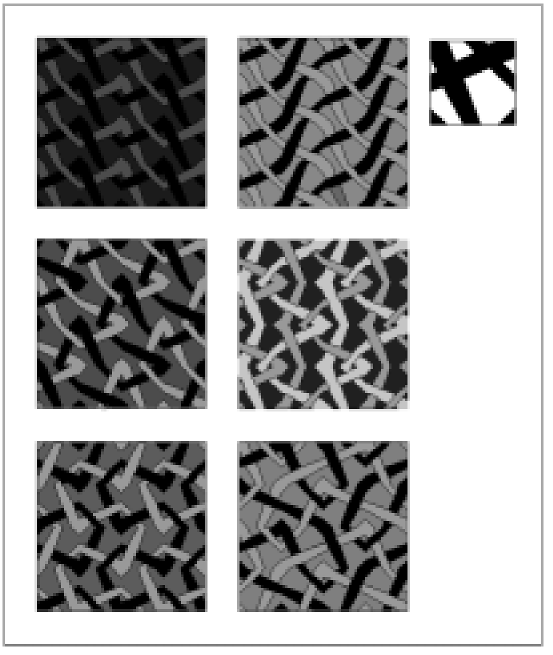


**Figure 5.2: The prototile for ornamental knotworks by M.C.Escher (Schattshneider 1990)**

The cover of this dissertation also illustrates the use of modularity in art. The 16 tiles can be put together in a myriad of ways; they always fit together because of the standard interface between the tiles. In art, different modules (e.g., bricks in architecture or in ornamental brickwork) occur as the basis of modular structures. In various fields of (discrete) mathematics, the important problem is the recognition of some set of basic elements, construction rules and an (exhaustive) derivation of different generated structures.

In a general sense, the modularity principle is a manifestation of the universal principle of economy in nature: the possibility for diversity and variability of structures, resulting from some (finite and very restricted) set of basic elements by their recombinations. In many cases, the derivation of discrete modular structures is based on symmetry. Using the theory of symmetry and its generalizations (simple and multiple antisymmetry, colored symmetry...) for certain structures it is possible to define exhaustive derivation algorithms, and even to obtain some combinatorial formula for their enumeration (Jablan 1996).

**Modularity in object-oriented programming**

Object-oriented programming, like most interesting new developments, builds on some old ideas, extends them, and puts them together in novel ways. An object-oriented approach makes programs more intuitive to design, faster to develop, more amenable to modifications, and easier to understand. It leads not only to new ways of constructing programs, but also to new ways of conceiving the programming task. Object-oriented programming develops “object” modules that can be combined to create customized applications programs (Cusumano 1991).

Identifiable object-oriented modeling languages began to appear between mid-1970 and the late 1980s as various methodologists experimented with different approaches to object-oriented analysis and design. By the mid-1990s, new iterations of these methods began to appear and these methods began to incorporate each other’s techniques, and a few clearly prominent methods emerged. Unified Modeling Language (UML) is probably one of the most well-known and widely-accepted of these methods. As the strategic value of software increases for many companies, the industry was looking for techniques to automate the production of software and to improve quality and reduce cost and time-to-market. These techniques include component technology, visual programming, patterns and frameworks. Additionally, the development for the World Wide Web, while making some things simpler, has exacerbated these architectural problems. UML was designed to respond to these needs (see http://www.omg.org).

Object-oriented programs have a natural modularity that makes them easier to develop and maintain than purely procedural programs. To a object-oriented programmer, a “module” is nothing more than a file containing source code. Breaking a large (or even not-so-large) program into different files is a convenient way of splitting it into manageable pieces. Each piece can be worked on independently and compiled alone, then integrated with other pieces when the program is linked (NeXT Software 1996).

**Modularity of the Mind**

In his 1983 publication ‘The Modularity of Mind’ Fodor argues that the mind is assembled into two fundamentally different systems. The central processor houses our intentional states (Fodor 1983:103). It handles the task of fixing belief, mediates the production of speech and acts as an interface to an array of input systems. Conversely, input systems or "modules" as described by Fodor provide information about the environment in a format appropriate for central processing (1983:44). Modules are domain specific computational engines interfacing between the environment and the central processor. Fodor imagines these modules as representing our perceptual systems (including language). Since Fodor’s publication, modules have been imagined to handle the semantics and syntax of language, vision and auditory mechanisms and more recently, reasoning behind mate selection and social interaction.

The modular approach to grammar has been shown to have important consequences for the study of language. Within such an approach, the properties of specific rules (passive, normalization etc.) are derived from the interaction of general principles, and in this way a greater explanatory adequacy is obtained. Another important aspect of the modular approach is that it focuses research on the properties of modules, the interface levels, and the overall architecture of the grammar, making these notions more precise. Modular grammar consists of a system of several independent components (for example, syntax, phonology, semantics and so on), each which is governed by its own principles and parameters (Di Sciullo 1997). The system of grammar put forth in Chomsky (1986) is modular in the sense that “the full complexity of observed phenomena is traced to the interaction of partially independent subtheories, each with its own abstract structure.”

### 5.2.4 Modular systems: a summary

When we try to summarize the previous discussion on modular systems in general, a number of features and properties of modular systems are most apparent. The first is the loose coupling between the elements (or modules). The second is the need for these elements to be distinct from each other, often with clearly defined functions. The third property of a modular system is the relative ease of separation and recombination of the modules, with as a consequence the possibility to construct a large collection of different, heterogeneous system structures. It may be argued however, that the third property is not so much a property but more of a result of a modular system: *because* it is modular, it can be easily separated and recombined. The same is true for the notion that modularity may create diversity and variability of systems and structures.

Furthermore, we noticed many different terms used interchangeably which at first sight referred to the same concept. These terms are modules, parts, components, entities, elements and later in this chapter we will also find that the term chunks is used. We do not think that we need to make a clear distinction between all of these terms; they are indeed mutually interchangeable, although the term chunks may be reserved for physical products. The other terms are merely different words for the same concept, i.e. the building blocks of an entire system, so we will continue to use them alternately.

This brings us a little further – especially the work of Schilling (2000) proved to be very helpful - although we still have neither found a concrete definition or measure for the degree of modularity of a system (Schilling only discusses the *increase* of modularity of a system), nor a clear feeling about how to apply modularity in a business environment. The following section will shed more light on this.

## *5.3 Three-Dimensional Business Modularity*

In the following sections we extend the general discussion on modularity and modular systems in general towards a more specific focus on business modularity in particular. We elaborate on three dimensions of modularity: product, process and supply chain modularity. Before the theoretical background and implications of each of these dimensions is discussed, we will present a number of empirical business examples which may be supportive in understanding the concept of business modularity better.

### 5.3.1 Examples of business modularity

Numerous examples exist in scientific literature which typify products, processes, organizations or networks as modular. Sanchez & Mahoney (1996) offer a nice overview, just as Ulrich & Eppinger (1995) and Baldwin & Clark (1997). We summarize their contributions and several others in the following table.

| Product | Description | Reference |
|---|---|---|
| **Bicycles** | The bicycle is a modular product. Each component has a specific role and manufacturers may try to fulfil that role in different ways.<br>National Bicycle of Japan uses a modular architecture to provide bicycles customized to the size and body proportions of individual customers. | Galvin (1999)<br><br>Kotha (1995) |

| | | |
|---|---|---|
| **Aircraft** | Common wing, nose and tail components allow several models to be leveraged by using different number of fuselage modules to create aircraft of different length and passenger/freight capacities. | Woolsey (1994), Sanchez & Mahoney (1996) |
| **Home appliances** | General Electric leverages several models of dishwashers by installing different doors and controls on common assemblies of enclosures, motors and wiring harnesses.<br>Electrolux recently tested a concept of mass-customizing refrigerators by letting customers chose between 15000 combinations of colors and materials, such as between stainless steel or wooden shelves. | Sanchez (1999)<br>Worren et al. (2000) |
| **Consumer Electronics** | Over 160 variations of the Sony Walkman were leveraged by 'mixing and matching' modular components in a few basic modular product designs. | Sanderson & Uzumeri (1990) |
| **Personal Computers** | Personal computers often consist largely of modular components such as hard disk drives, flat screen displays and memory chips, coupled with some distinctive components such as a microprocessor chip and enclosure. | Langlois & Robertson (1992) |
| **Automobiles** | Automakers have long used many basic modular components specified by the Society of Automotive Engineers.<br>Volkswagen uses a modular approach in its new truck factory in Resende, Brazil. The company provides the factory where all modules are built and the trucks are assembled, but the independent suppliers obtain their own materials and hire their own workforces to build the separate modules. | Nevins & Whitney (1989)<br>Baldwin & Clark (1997) |
| **Watches** | Swatch uses a modular architecture to enable high-variety manufacturing | Ulrich & Eppinger (1995) |
| **Power Tools** | Black and Decker designed its entire line of power tools in the 1980s to incorporate a high degree of common modular components. | Utterback (1994) |

**Table 5.2: Examples of modularity in a business environment**

Once again, the concepts of high-variety and mixing-and-matching come up in these examples. Further, the relation between *common* elements and *various* models is apparent as well. We continue our discussion by focusing on modular products in more detail.

## 5.3.2 Modular products

Most products are very complex and ill-defined; within each product level, many components may be linked to form the next higher level (Simon 1962, von Hippel 1998). This is especially true for customized products, while consumers may add certain attributes and drop others, or they may combine the product with another product that had been generally regarded as distinct. Alternatively, a product that consumers had treated as an entity may be divided into a group of subproducts that consumers can arrange into various combinations according to their personal preferences (Langlois and Robertson 1992). Because of this, it has been very hard to come up with an undisputed measurement of the modularity of a product, while each product is in fact different from the other. This may, for instance, lead to numerous (nested) levels of modularity within a single product.

Henderson & Clark (1990) distinguish between the components of a product and the ways they are integrated. The latter is defined as the product architecture; it is the scheme by which the functional elements of the physical product are arranged into physical chunks and by which the chunks interact (Ulrich & Eppinger 1995). The *functional elements* of a product are the individual operations and transformations that contribute to the overall performance of the product. The *physical elements* of a product are the parts, components and subassemblies that ultimately implement the product's functions. According to Ullrich and Eppinger (1995), a product architecture is fully modular if a 1:1 mapping exists between functions and physical components and de-coupled physical interfaces between interacting components. This means that a change made to one component does not require a change to other components for a correct functioning of the total product. A modular architecture has the following two properties:

- Chunks (modules) implement one or a few functional elements in their entirety
- The interactions between chunks are well defined and are generally fundamental to the primary functions of the product.

Modularity is a relative property of a product architecture. Products are rarely strictly modular or integral. Rather, we can say that they exhibit either more or less modularity than a comparative product (Ulrich & Eppinger 1995).

Fine (1998) summarizes the most essential differences between a modular and an integral product architecture. A modular architecture features separation among a system's constituent parts, whereby:

- Components are interchangeable
- Component interfaces are standardized
- System failures can be localized

In contrast, an integral product architecture might feature, for example:

- Components that perform many functions
- Components that are in close proximity or close spatial relationship
- Components that are tightly synchronized

Baldwin & Clark (1997) do not give a clear definition of modularity, instead they identify three types of product modularity: *modular-in-production, modular-in-design* and *modular-in-use*. Modularity-in-production rationalizes a product into components and allows parts to be standardized (e.g., all screws the same size) and produced independently before assembly into the final system. Modularity-in-design goes a step further: with an overall architecture and standard interfaces, the modules can be designed independently, and mixed and matched to create a complete system. Finally, a product is modular-in-use if consumers *themselves* can mix and match components to arrive at a functioning whole. This typology, once again, shows two factors are of importance: independence of components and standardization of interfaces. Both factors together, allow either the producer or the customer to mix-and-match the components and come up with many variations of the end-product.

In their later work, Baldwin & Clark (2000) elaborate further on modular design of products. They define a module as 'a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units.

Clearly there are degrees of connection, thus there are graduations of modularity.' (Baldwin & Clark 2000: 63). In other words modules are units in a larger system that are structurally independent of one another, but work together. Their definition has been adapted from McClelland & Rumelhart (1995). Baldwin & Clark state that after some analysis, they had to conclude that it is difficult to base a definition of modularity on functions, like Ulrich's (1995: 422), which are inherently manifold and nonstationary.

According to Baldwin & Clark (2000), when modularizing a design, one has to address three categories of design rules:

- *Architecture*, i.e., what modules will be part of the system, and what their roles will be;
- *Interfaces*, i.e., detailed descriptions of how the different modules will interact, including how they will fit together, connect, communicate, and so forth;
- *Integration protocols and testing standards*, i.e., procedures that will allow designers to assemble the system and determine how well it works, whether a particular module conforms to the design rules, and how one version of a module performs relative to another.

Finally, O'Grady (1999: 154) introduces granularity, which refers to the functionality of a module. According to O'Grady, a large module, with a high degree of functionality, can be thought of as having *coarse* granularity, while the converse be thought of as having *fine* granularity. In the case of coarse granularity, products can be configured with relatively few modules. With fewer modules, then the number of joins between modules is lower than with a finer granularity. Subsequently, the product variety with coarse granularity modules will be lower than with fine granularity.

In summary, we learned that the mapping between functions and elements is essential: a 1:1 mapping denotes modularity, while a more complex mapping indicates integrality. Although Baldwin & Clark (2000) conclude that it is difficult to base a definition on functions, we follow the line of reasoning of Ulrich (1995). Concepts such as granularity (O'Grady 1999) and module attributes (Langlois & Robertson 1992) are in line with the function perspective. Further, the interactions, or interfaces, between the modules are of great significance as well, together with the interdependencies between the modules and the connectedness within the modules. Standardized module interfaces enable the easy separation and recombination of modules.

### 5.3.3 Modular processes

A process can be defined as 'a set of interrelated tasks to achieve a certain goal' (Davenport & Short 1990). Another similar definition comes from Turney (1991): 'a series of activities that are linked to perform a specific goal'. They refer to the technologies and procedures used to produce or deliver products or services within an organization (Boynton & Victor 1991).

Feitzinger & Lee (1997) argue that breaking down the production process into independent subprocesses provides companies with the kind of flexibility that effective mass customization requires. Such an approach is based on three principles: process postponement, process resequencing and process standardization. The three features indeed closely resemble earlier-mentioned features of modular systems and products. The distinctiveness of process elements, their loose coupling and ease of switching and recombination indeed are apparent. Fine (1998) further elaborates on the coupling between process modules and introduces two dimensions in which the coupling between the modules can be defined: time and place. When the coupling between the process components decreases in time and/or place, the process becomes more modular. When certain process components are executed at a different moment or location, decoupled from the other process components, then process modularity increases. An example is the prefabrication of certain product components or the dispersion of teams to different locations.

In apparel, automotive and the housing industry more and more companies start making use of modular manufacturing. Especially in the apparel industry it has received wide attention. The American Apparel Manufacturers Association (AAMA) has defined modular manufacturing as "a contained, manageable work unit of five to 20 people performing a measurable task. The operators are interchangeable among tasks within the group to the extent practical, and incentive compensation is based upon the team's output of first quality products." Some of the principles of modular manufacturing are:

1. Production employees should be formed into well integrated work groups of 5-20 people;
2. Modular groups should choose a natural leader who is their principal interface with the next level of supervision;
3. Modular groups should be given considerable latitude in performing specific work tasks and in machine and work assignments (Schroer et al. 1992).

To reach its cost and speed objectives, the auto industry is also moving to "modular production." Parts from thousands of tier I and II manufacturers are being consolidated into large subassemblies by subcontractors, leaving just the final steps of assembling the car in the factory (Van Hoek & Weken 1998). To save time and money, such "modules" could eventually be put together "in-transit," avoiding costly physical facilities owned by the automakers. The retail dealer potentially may become the place of final assembly, thus moving manufacturing as close to the final customer as possible (Oliver 2000).

We thus observe that in itself, a process, such as a production process or a distribution process, can become more or less modular too. When the coupling between the different process components decreases and the components become more distinct from each other, the process in itself becomes more modular. Sanchez (1997) elaborates on the previously given definition of architecture by Henderson & Clark (1990) and extends it to the level of the business process. In his opinion, process architectures are conceptually analogous to product architectures. A modular approach intentionally tries to create a product or process design that permits the “substitution” of different versions of functional components for the purpose of creating product or process variations with different functionalities or performance levels (Sanchez 1997).

When this analogy is indeed true and valid, the previously defined features and properties of modular systems and products should be applicable to processes as well. Only the issue of standardization of interfaces, could need some further elaboration. Exactly, what is meant by a process interface? In general, how do process components interact or connect with each other? To what extent can these interfaces subsequently be standardized?

### 5.3.4 Modular supply chains

Another type of modularity is only recently coming into attention, i.e. the modularity of supply chains and business networks (Baldwin & Clark 1997, Venkatraman & Henderson 1998, Fine 1998, van Hoek & Weken 1998). The idea is that not only products and production processes can be modularized, but modularity can also be applied in a supply chain setting. In analogy with modular products and modular processes, modular supply chains permit the "substitution" of different versions of functional components for the purpose of creating supply chain variations with different functionalities or performance levels.

In this session we will once again elaborate on whether the previously mentioned features and properties of modular systems, products and processes can be applied on supply chains (or business networks as well). Before we do that however, we first need to discuss the differences between a process and a supply chain. The reason to do this is that many authors (like Sanchez & Mahoney 1996) do not explicitly distinguish between these two dimensions. Often they merely combine both dimensions by stating that both intra- and interorganizational processes exist and that they possess the same features. We tend to disagree with this and explicitly want to distinguish between the two. In our case, processes refer to the technologies and procedures used to produce or deliver products or services within an organization (Boynton & Victor 1991), while a supply chain refers to the choice and design of the network surrounding an organization. The former says something about *how* the product is made or manufactured, while the latter refers to *who* does it. Obviously, both concepts are interrelated but distinguishing between the two offers the opportunity to explicitly focus on interorganizational relationships, coordination mechanisms, outsourcing and make-or-buy decisions (Fine 1998).

As mentioned above, the opposite of modular is integral. Supply chain integration has achieved a lot of attention in literature. "Supply chain integration links a firm with its customers, suppliers and other channel members. As such, it integrates their relationships, activities, functions, processes and locations." (Bowersox & Morash 1989). Morash & Clinton (1998) argue that supply chain integration supports the movement from conventional, arms-length and often conflict-laden relationships to cooperative, long-term business partnerships and strategic alliances. They come up with a measurement instrument to determine the degree of integration of a supply chain. The items they use are:

- Sharing information is crucial in supplier relationships
- Frequently measure suppliers' performance
- Frequently share performance results with suppliers
- Form strategic alliances with material suppliers
- Form strategic alliances with logistics service suppliers

Some of these measurements indeed correspond with the opposites of earlier-mentioned properties of modularity (alliances: tight coupling), but most them could also be applicable for modular supply chains as well. That is, frequent performance assessment and sharing of performance results can just as well be done in modular supply chains. It seems as if integration here is not so much the opposite of modularity but merely synonymous with frequent communication and sharing of information.

Let us therefore discuss another perspective, which does incorporate both integrated as modular supply chains. Collins & Bechler (1999) come up with a number of basic features of both an integrated supply chain and modular consortia. They are given in table 5.3 below:

| | **Integrated supply** | **Modular consortia** |
|---|---|---|
| **Suppliers** | First tier | Co-investors |
| **Location** | Onsite "hole-in-the-wall", with no geographic constraint | Online, with no geographic constraint |
| **Relationship** | Interdependent | Dependent |
| **Logistics** | Increasing efficiency | Increasing efficiency |
| **System flexibility** | Limited ability to reconfigure | Limited ability to modify partnership |

**Table 5.3: Comparison of integrated supply chains and modular consortia (Collins & Bechler 1999)**

Immediately, we see the great variety in using the concepts of modularity and integrality. These authors focus on five aspects: type of suppliers, location, relationship, logistics and system flexibility. No direct connection seems to be present with the earlier features of modularity in general. On the contrary, dependent relationships between the modules seem somewhat contradictive with earlier findings. The distinction between first tier (integral) and co-investors (modular) corresponds better with the degree of coupling of the modules. We thus continue our search and arrive at the work of Aldrich (1978), which confirms our findings about the hard-to-define concepts of integrality and modularity.

Aldrich (1978) states that integration (of networks) is an ill-defined concept, making operationalization difficult and interpretation of outcomes confusing. Integration was generally considered to focus on issues of both interconnectedness among provider agencies and the extent to which provider agencies are integrated and coordinated through a central authority. Provan & Millward (1995) operationalize integration in line with the general network structure concepts of density (cohesion in a graph) and overall centralization (organization around particular focal points). Density is simply a measure of the extent to which all network organizations are interconnected. Centralization refers to the power and control structure of the network, or whether network links and activities are organized around any particular one or small group of organizations. According to Provan & Millward (1995) a high density and centralization refers to a high degree of integration. The opposite, low density and de-centralization, should therefore indicate a modular network.

The concept of density and connectedness is also used by Fine (1998), who introduces the proximity of elements to determine the degree of modularity (or integrality) of a supply chain. He argues that an integral supply chain architecture features close *proximity* among its elements. Proximity is measured along four dimensions: geographic (physical distance), organizational (ownership, managerial control and interpersonal and interteam dependencies), cultural (language, business mores, ethical standards and laws, among other things) and electronic (e-mail, EDI, intranets, video conferencing etc). A modular supply chain exhibits low proximity along most or all of the dimensions listed above. For instance, modular supply chains tend to feature multiple, interchangeable suppliers for key components (Fine 1998).

We also saw that centrality and ways of coordinating the supply chain actors, are related to the degree of modularity of a supply network. From the field of coordination theory we can thus further analyze its features. The choice of coordination strategy is crucial in managing the interorganizational relationships. Coordination strategy is the process by which strategic choices are made for coordinating economic activity with trading partners and includes, for example, the choice of trading partners and types of relationships developed with them (Holland & Lockett 1997). Numerous studies have been carried out that discuss the question which coordination mechanisms are most efficient and effective dependent on the structure of the network and which contingent variables further influence the choice of the best mechanism (e.g., March & Simon 1958, Thompson 1967, Grandori 1997).

The question now rises which type of interorganizational relationship is displayed by a modular or an integral network or supply chain. Subsequently, one can ask which type of coordination mechanism is most effective in each situation. Sanchez & Mahoney (1996) offer an answer by stating that in a loosely coupled system each participating component can function autonomously and concurrently under the embedded coordination of a modular product architecture. This corresponds closely to Daft and Lewin's (1993) notion of a modular organization that continuously changes and solves problems through interconnected coordinated self-organizing processes and Weick's (1976) loosely coupled systems where 'the tasks […] are intentionally designed to require low levels of coordination so that they can be carried out by an organizational structure of quasi-independent entities functioning as a loosely coupled system.' Fine (1998) also sees the analogy between modularity and a coordination strategy. 'Real competitive advantage could be made by individual organizations that know best how to design and coordinate their supply chain, i.e. how to efficiently source supply chain modules. The ultimate core competency is the competency of deciding which capabilities (modules) to make and which to buy, which are core and which are peripheral.'

### 5.3.5 Summary: Defining Modularity

In the previous sections we saw that several different perspectives and definitions of modularity (and integrality) exist. On the other hand, we were also able to unveil a number of so-called key characteristics and features of modular systems in general, and modular products, process and supply chains in particular. The following features were distinguished that are of importance to determine the degree of modularity:

- Distinctiveness/autonomy of components
- Loose coupling between modules; tight coupling within modules
- Clarity of mapping between functions and components
- Standardization of interfaces
- Low levels of coordination (self-organization; coordination embedded in the architecture)

Combining these features into one single definition is a little awkward but one could argue that:
*A system is modular when it consists of distinct (autonomous) components, which are loosely coupled with each other, with a clear relationship between each component and its function(s) and well-defined, standardized interfaces connecting the components, which require low levels of coordination.*

The modularity of a system decreases when one or more of these conditions fail to hold.

The first issue is distinctiveness of components, originating from the work of Weick and his colleagues on loosely coupled systems. We combined distinctiveness with autonomy while Orton & Weick argue that responsiveness of the system's components is just an important feature of loose coupling and we believe that autonomy is a very good indicator of this variable. Especially for processes and supply chains, autonomy is a better indicator than distinctiveness. In the case of products, distinctiveness will be used.

The second feature is the loose coupling between modules whereas the modules are tightly coupled within themselves. This feature builds forth upon the previous feature, with the addition that the modules themselves can be seen as black boxes, i.e. we do not need to know the inner structure or functioning of the modules in order to be able to use the modules.

Third, a modular design is characterized by a clear mapping between the components and their functions. Ullrich introduced this feature and argued that a 1:1 mapping is most clear and typifies a modular architecture while a more complex mapping, say n:m, denotes integrality. In the latter case many (n) functions are performed by many (m) components; their exact allocation (mapping) is unclear however.

Such a clear mapping of functions and components is often combined with standard and well defined interfaces between the modules. That is, the way the modules interact or come together is predefined and clear. Standardization of interfaces also enables the easy interchange of modules that make use of the same interface. It further enables easy separation and recombination of the modules. In the case of process and supply chain modularity, these interfaces could refer to contracts, transaction protocols, operating procedures and input/output agreements.

Finally, it was argued that modular architectures exhibit low levels of coordination, thus enabling self-organizing of the modules. Coordination is, in other words, embedded within the architecture. In this respect, coordination of product modules may be somewhat ill-defined. What exactly is meant by coordinating product modules? In product development literature this often refers to the process of developing a new product, i.e. the process of specifying design rules, initial design, fabrication, prototype testing, final design etc. (Baldwin & Clark 2000). We do not wish to follow this path while we would end up in the field of product engineering, which is fairly outside our fields of organization and information science. Instead, we follow the line of reasoning of, among others, Sanchez (1999), Schilling (2000), Worren et al. (2000) and O'Grady (2000), who focus on the end-result of this process, the product offered to the customer. Coordination in this respect simply refers to "managing dependencies", as defined by Malone and Crowston (1994) and Crowston (1997). In the case of product modules this is very similar to the second modularity feature ‘loose coupling between modules; tight coupling within modules’ and thus becomes somewhat redundant. Therefore, we omit low levels of coordination from the product modularity definition.

Not only are we now able to determine the degree of modularity of a ‘business system’ (being either a product, a process or a supply chain), the next thing for us to do is consider the benefits of actually using a modular approach as opposite to a more integral one. First, this means that we need to elaborate on the usefulness and appropriateness of designing each dimension in a modular fashion and under which conditions this is indeed the best thing to do. Second, we want to investigate whether a concurrent design of all dimensions (product, process *and* supply chain) is preferable to a more independent approach where all three dimensions are designed independently of each other. The former topic is of interest for the sections 5.4 and 5.5, the latter will be discussed right away in the next section – 5.3.6.

### 5.3.6 Modularity in three dimensions

Fine (1998) claims that product, process and supply chain architectures tend to be aligned along the integrality-modularity spectrum. That is, integral products tend to be developed and built by integral processes and supply chains, whereas modular products tend to be designed and built by modular processes and supply chains. They tend to be mutually reinforcing and conducive to each other. The concurrency between processes and supply chains is also addressed by Feitzinger & Lee (1997) who state that manufacturing processes should be designed such that they, too, consist of independent modules that can be moved or rearranged easily to support different distribution-network designs. This topic is closely related to the field of concurrent engineering. Concurrent engineering, according to the Institute for Defense Analysis (Handfield, 1994: 385), refers to "a systematic approach to the integrated concurrent design of products and related processes including manufacture and support. With concurrent engineering all activities required to bring a product to market - marketing, design, engineering, and manufacturing - are jointly managed to work in parallel; this in sharp contrast with the traditional "throwing it over the wall" approach (Hoedemaker et al. 1999). That is, a typical company, much like a medieval castle, constructed protective walls around certain groups, functions or departments, in effect keeping out people who did not belong. The concurrent process has been characterized by Takeuchi and Nonaka (1986) as the "rugby team" approach to design instead of the sequential "relay race" approach.

Where concurrent engineering only focuses on products and processes, we follow Fine's (1998) line of reasoning and add the dimension of the supply chain to the former two. It is hypothesized that a concurrent design in these three dimensions leads to better results and performance than a more asynchronous approach. The main objective of this research module is to investigate whether and under which circumstances this hypothesis is indeed valid. The starting point is Fine's observation that product, process and supply chain architectures tend to be aligned along the integrality-modularity spectrum. We will try to make the connection between this alignment and firm performance, in particular mass-customization. We will also try to shed light on the external conditions for applying such a strategy, i.e. identify factors to strengthen or limit the use of a concurrent, modular design. For this purpose we can use the previously described overview of literature on modularity in all of these dimensions, including the operationalization of the concepts. In the following sections we will first discuss the contingent factors, followed by an elaboration on modularity and firm performance.

## *5.4 Contingent factors*

This section elaborates on a number of factors which may influence the optimal or desired degree of modularity of a business, i.e. its products, processes and supply chain. Three main factors were found in the literature: customer disposition to participate, competitive environment (denoted as clockspeed) and technological feasibility (such as the use of ICT). These factors will be discussed in the following sections.

### 5.4.1 Customer disposition to participate

The essence of (mass) customization is that customers should be allowed to customize their products or even more, be involved in the design of the production processes and supply chains. The degree of customization or personalization should be as high as possible (or necessary), without the loss of efficiency and effectiveness. As an organization, one should however wonder whether their customers actually care about this type of service (Hart 1996). Do they want to spend time on choosing between all the different options offered and are they sophisticated enough to make these decisions at all? If customers do not care about variety and do not want to participate in the design process, chances are high that mass-customization is not the right strategic choice for an organization. Hart calls this customization sensitivity, Larsson & Bowen (1989) denote this as the customer's disposition to participate in the design. We will use the latter definition.

Lampel & Mintzberg (1996) come up with a typology of customizations, based on the characteristics and variety requirements of the customers who should buy the product. The three strategies (next to pure standardization and pure customization) are:

- Segmented standardization: where the market is divided into recognizable segments, and each segment is offered different options
- Customized standardization: where customers are offered components of the product and they can customize them to fit their needs, either by themselves or by the retailer.
- Tailored customization: where the customer is presented with a prototype and then personal information is solicited and the product is tailored to specifications.

Huffman & Kahn (1998) also note the limitations of unlimited variety by arguing that the optimal amount of variety to be offered depends on the competition and customer values in a particular industry. The mere consideration of the question how much variety to offer suggests that there may be such a point where there is *too* much variety. Large assortments can be perceived as negative by consumers, if instead of offering possibilities and choice, they seem monumental and frustrating. Although consumers nowadays have become much more autonomous and individualistic, a recent study by Schwartz (2000), published in the American Psychologist, shows that there is another side to this. Schwartz claims that our contemporary culture has gone too far in stressing freedom and autonomy. Consumers are given too much freedom of choice, which makes them unhappy and depressed. Experiments show that if people only need to choose from a few alternatives, they are more satisfied with their choice. For most people in the world, Schwartz argues, individual choice is neither expected nor desired.

Furthermore, if it is difficult for a customer to choose appropriate components, or to assemble those components into the product configuration, then a non-modular product may offer additional functionality by eliminating the selection and assembly responsibilities of the customer. In order for a customer to choose components of a modular system, the customer must be able and willing to distinguish among the performance, quality and value attributes of different components (Schilling 2000). This frequently means that a customer must have understanding of how the components function individually as well as how they work together and interact. When products are very complex this may be more difficult for customers.

In line with the previously mentioned studies, we will divide customer disposition to participate in the following three variables: heterogeneity of demand, customer ability and customer willingness to be involved in design and assembly of the product at hand. Both will most likely positively influence the need for using modularity.

Heterogeneity of demand refers to the divergence in different product variations, types and attributes customers require. These include items such as color, size, shape and volume of the (physical) product. It may also concern additional services, such as insurance, guarantees and repairs, or requirement with respect to the other two levels of the business network: process and supply chain. There may be customers demanding influence on the way the product is produced: which type of production methods and techniques are used, how is the product distributed? Furthermore, customer demands may differ with respect to supply chain modules. Do customers actually care about who, or what organization, is involved in the design, production, assembly and distribution of the product or service? Examples of such heterogeneity can be found at hairdressers where customers often prefer their hair to be cut by a specific employee or in the transport sector, where shippers favor dedicated organizations for specific parts of the handling process. This means that a product no longer may be considered as just the physical good or service, it could also include the back-office operations and the people or organizations involved. Each customer for himself should decide to include these dimensions in the product or not. The heterogeneity of demand therefore, not only reflects the differences in required choice options, but the differences in the depth and level of impact of these options as well.

The other variable belonging to the customer’s disposition to participate is the customer’s ability to do just that. Ability means that a customer must have understanding of how the components of the system work both individually and in interaction. For simple products, this ability will most likely be higher than for more complex products, as argued by Schilling (2000). The confidence of the customer in its own skills will likely decrease. In the latter case, customers may need additional support, offered by external sources or intelligent computer systems. The motivation of a customer to participate in the design will most likely be closely related to its own ability and sophistication. Furthermore, the more sophisticated and experienced the customer, the more likely his need to choose process and supply chain modules as well. Advanced audio equipment customers, for instance, often assemble their own system by purchasing individual components from multiple vendors, in order to come up with a system that closely matches their needs and price requirements.

Finally, the willingness (or desire) of a customer to participate in the design or to choose between numerous configuration options needs to be considered as well. Variety should be desired by the customers, otherwise it is a useless service to them.

### 5.4.2 Clockspeed

The concept of clockspeed was first introduced by Fine (1998). It refers to the rate of change in the industry's external (competitive) environment, including developments in technology, consumer preferences and market conditions. Fine bases its concept on the fruit flies, which are used in medicine for research on genetic codes. Biologists study fruit flies because their genetic structure is similar to that of humans, and because, despite their genetic complexity, they evolve rapidly. Fruit flies are, so called, fast-clockspeed species. The concept of clockspeed can also be applied to business. According to Fine, each industry evolves at a different rate, depending in some way on its product clockspeed, process clockspeed and organization clockspeed. The information-entertainment-industry, for example, is one of the fastest clockspeed fruit flies of the business world. Its product can have half-lives measured in hours, if not days (Fine 1998:6). Furthermore, the IT industry is characterized by a high clockspeed. It possesses a remarkable decline in price/performance ratios and compression of product life-cycles (Mendelson & Pillai 1998).

The concept of clockspeed is of high interest for investigating modularity while it is often claimed that a key issue surrounding modular strategy is understanding the industry you are in: is it stable, dynamic or evolving? Starr (1965) already states that industries with short life cycles will react earlier to possibilities for modular production. In other words industries with high clockspeeds may profit more from a modular strategy. Furthermore, Schilling (2000) finds a strong relationship between external pressures, like the speed of technological change and competitive intensity, and the need for a system to become more modular. She calls this the urgency in the context of the system.

Curry & Kenney (1999) study the highly dynamic PC industry and state that the relation between clockspeed and modularity can also be reversed. The modular nature of PC production and the availability on the open market has led to competition at nearly every stage of the value chain. The modular nature of PCs means that the specifications for linking various components are freely available. Moreover, no single company in the PC value chain integrates the entire chain and there is competition at (almost) every link of the chain; the value chain is disaggregated as well. This leads to a very dynamic environment with a rapid rate of change, frequent introduction of new components and constant improvements in performance. A disaggregated value chain and a modular product mean that it is in the interest of every part of the value chain to encourage new competition in other segments of the chain. As one can see, clockspeed and modularity are strongly correlated in this industry. We expect a same type of relationship in other industries as well.

For a more detailed analysis of the clockspeed of an industry we strongly rely on the work of Fine (1998) and Mendelson & Pillai (1998). Fine himself admits that 'although intuitively appealing and strategically valuable at a conceptual level, the *measurement* of clockspeed is fraught with complexity at all levels, from the technology, to the firm, and ultimately to the entire industry.' Measuring clockspeed is in its infancy. Fine comes up with a suggestion for measurement, along the dimension of product technology, process technology and organization. Table 5.5 summarizes a few of the sample industries Fine studied in this respect:

| Type of Clockspeed Industry | Product technology clockspeed | Organization clockspeed | Process technology clockspeed |
|---|---|---|---|
| **Fast clockspeed** | | | |
| **Personal computers** | <6 months | 2-4 years | 2-4 years |
| **Toys and games** | < 1 year | 5-15 years | 5-15 years |
| **Medium Clockspeed** | | | |
| **Bicycles** | 4-6 years | 10-15 years | 20-25 years |
| **Automobiles** | 4-6 years | 4-6 years | 10-15 years |
| **Slow Clockspeed** | | | |
| **Aircraft** | 10-20 years | 5-30 years | 20-30 years |
| **Tobacco** | 1-2 years | 20-30 years | 20-30 years |

**Table 5.5: Overview of clockspeeds of different industries (Fine 1998)**

Product technology clockspeed stands for changes in dominant design, the frequency of change in options packages or the frequency of change in a given model. For process technology clockspeed one can measure by rate of introduction of dominant process/organization paradigm (mass production, lean production etc.), by age of factory equipment or by introduction of some new process technology in one area of the factory. For organization clockspeed one can assess the intervals between CEO transitions, organization restructurings, ownership changes, and the like. As mentioned above, Schilling (2000) indicates that urgency in the context of product systems increases the likelihood of the system responding to pressures to become more modular. The primary factors that create urgency are, in her opinion, the speed of technological change and competitive intensity. The former corresponds with Fine's product and process technology clockspeed, while competitive intensity can be compared with organization clockspeed.

### 5.4.3 Technological Feasibility: Use of ICT

Applying modularity is often a complicated and complex task. Developing the individual modules and assembling them requires knowledge and information about the individual modules and the way they interact with other modules. Baldwin & Clark (1997) stress that modular systems are much more difficult to design than comparable interconnected or integral systems. An organization must be technologically capable to manage this increased (informational) complexity. If not, using modularity will not lead to the desired effects, such as innovation and customization, but instead will increase costs or decrease quality of the product or process. A less modular design is in this case preferable.

In traditional business models mass-customization, even in combination with modularity, is always more expensive or less profitable than fewer customization with integral designs. The advent of information technology has made it much more cost-effective to address individual customers' needs. It is hypothesized that only by using ICT in an efficient manner can one remove the cost-flexibility paradox. ICT can be used to link the different modules (being either product, process or supply chain modules), coordinate their development and execution or automate the modules themselves (Pine 1993). One could think of the use of multi-media systems to enable clients to build their car in the showroom and for forwarding the order for the car to the distribution centers. Information technology and extensive databases allow the marketer to understand how likely a consumer is to buy in a new category, given his or her current purchases from the firm. Implementation of intelligent datasystems, such as point-of-sale datasystems and customer information systems are other options (van Hoek & Weken 1998). Furthermore, Nadler et al. (1992) point out that the creation of effective architecture hinges on the use of structural materials capable of implementing the architecture and stress ICT's power in creating future organizational architecture.

The use of modularity in combination with Product Data Interchange (PDI) also offers potential advantages. PDI requires that one works on the bases of product models (information modeling), instead of mutual exchange of documents (data modeling). For these purposes it is necessary to:

- Establish a definition of what information constitutes a complete definition of a product;
- To gain acceptance of the developments of such a standard information model and
- To improve implementation of computer technologies for support of these developments (Wilson 1993).

This is easier to accomplish when products are built from distinct well-defined modules with well-defined functions.

## *5.5 Modularity and Business Performance*

### 5.5.1 General advantages of modularity

Baldwin & Clark (2000) claim that modularity does three basic things:

1. Modularity increases the range of "manageable" complexity. It does this by limiting the scope of interaction between elements or tasks, thereby reducing the amount and range of cycling that occurs in a design or production process.
2. Modularity allows different parts of a large design to be worked on concurrently.
3. Modularity accommodates uncertainty.

The first benefit refers to the fact that as the number of steps in an interconnected process increases, the process becomes increasingly difficult to bring to successful completion. Modularity thus reduces the range and scope of potential cycles. The second claim is based on the notion that because the independent blocks in a modular task structure can all be worked on simultaneously, the end-to-end time needed to complete a given process can be shortened. The third advantage stems from the idea that modules are 'black boxes', i.e. designers of certain modules do not need to worry about the other modules; the design rules of these latter modules are hidden and not required to work on the former.

O'Grady (1999) focuses especially on generic firm performance characteristics and argues that the benefits from modularity are widespread and include:

- Increased product variety and strategic flexibility

- Economies of scale
- Reduced order lead-time
- Lower capital costs
- Lower cost
- Decoupling task and design freedom
- Increased feasibility of product/component change
- The ease of product upgrade, maintenance, repair and disposal, faster product evolution and
- Simpler control

A number of these benefits have already been mentioned in this dissertation, a few others may require further explanation. For instance, lower capital costs refers to the fact that modularity can reduce the need for capital by allowing module integrators to obtain some modules “off the shelf” with no capital outlay required, or alternatively, to have the module providers furnish some or all of the capital required to produce their modules. Lower cost, in general, originates from the idea that the use of modularity allows module integrators to choose the “best of breed” module providers and allows for competition between module providers. This will reduce costs as module providers strive for competitive advantage. Decoupling task and design freedom and simpler control both refer to what Baldwin & Clark (2000) define as manageable complexity. The ease of maintenance, repair and disposal is closely related to the field of recovery management (Thierry et al. 1995), which deals with optimizing reverse logistics flows. A modular design enables better coordination and control of these return flows.

Langlois & Robertson (1992) define a modular product as follows, focusing on the role of the consumer of the product: consumers may add certain attributes and drop others, or they may combine the product with another product that had been generally regarded as distinct. Alternatively, a product that consumers had treated as an entity may be divided into a group of subproducts that consumers can arrange into various combinations according to their personal preferences. Whether or not there are economies of scale are possible, a product can be divided further and further into subproducts. In the extreme case of no economies of scale, the entire “product space” can be filled with products, and each consumer can have a product tailored to his or her requirements. A modular product – or rather a range of products - approximates this extreme; both the transaction costs of knowing the available parts and the scale economies of assembling the package are low for a wide segment of the user population (Langlois & Robertson 1992). Langlois & Robertson (1992) in particular addressed the economic benefits and conditions for applying product modularity: the role, requirements and heterogeneity of the customer together with possible economies of scale to be gained, determine to great extent whether a product should be modular (i.e. divided into many sub-products and elements) or not.

Sanchez & Mahoney (1996) agree with the first benefit mentioned by O’Grady by stating that modular product architectures can be an important source of strategic flexibility when they enable a firm to respond more readily to changing markets and technologies by rapidly creating product variations based on new combinations of new or existing modular components. Strategic flexibility is the capability of the firm to proact or respond quickly to changing competitive conditions and thereby develop and/or maintain competitive advantage (Lei et al. 1998, Hitt et al. 1998). Thomke & Reinertsen (1998) also argue that the flexibility of a design can be increased by developing a design architecture that minimizes interdependence between its individual components. They claim: "In practice, modularity alone is not enough to create flexibility; it matters greatly how you partition functionality within the design. […] It is not modularity itself that produces robustness, but rather modules that are loosely coupled to one another." (p.26-27).

Sanchez may be considered as one of the leading experts on modularity. In his 1999 article 'Modular architectures in the marketing process' he introduces modular knowledge architectures, which refers to the decomposition of the organization's knowledge into specific knowledge assets and the ways those knowledge assets interact in the organization's processes for creating and realizing products. He further summarizes four properties and strategic uses of modular architectures:

- Modularity enables the leveraging of product variations by substitution of component variations
- Modularity helps contain change by enabling common components to be used within and across product lines
- Modularity facilitates decoupling technology development and product development, enabling concurrent and distributed development processes
- Modularity enables the loose coupling of component designs and thereby creates loosely coupled knowledge domains.

Once again, advantages such as flexibility and variability, concurrency and loose coupling become apparent. In the next section we will focus our discussion on the advantages of modularity for mass-customization.

### 5.5.2 Modularity for Mass-Customization

One of the most evident benefits of modularity is the proposed ability to deliver mass-customized products and services. As we saw earlier in this dissertation, mass-customization is a synergy between mass production and customization. Mass-market goods and services are uniquely tailored to the needs of the individuals who buy them. Mass customization enables companies to customize individual offerings at little additional marginal costs. Without creating an overwhelming choice complexity or cost increase, it should provide customers exactly provide with what they want, for a value-for-money price level. Many diverse companies, such as BMW, Dell Computer, Levi Strauss, Mattel and McGraw-Hill, are adopting mass-customization and often, the World Wide Web plays an important role in this strategy. Hart (1996:12) argues that "the mass-customization strategy is most effective for those firms that have leveraged their agile manufacturing capability by developing an integrated companywide system that includes collaborative design processes (often using CAD or AI software), flexible production processes and "learning relationships".

Pine (1993) and his colleagues, like Gilmore and Anderson, address the use of modularity to achieve mass-customization. They distinguish six types of modularity, strongly based on the work of Ulrich & Tung (1991):

1. Component-sharing: same component is used across multiple products to provide economies of scope. Best used to reduce the number of parts and thereby the costs of an existing product line that already has high variety.
2. Component-swapping: different components are paired, opposite of component-sharing. Example: customizing services around a standard product. The key to taking advantage of component-swapping modularity is to find the most customizable part of the product/service and separate it into a component that can easily be reintegrated. Characteristics of the component: high value, easily re-integratable, great variety.
3. Cut-to-fit: Similar to the previous two types, but one or more of the components is continuously variable within preset or practical units. Most useful for products whose customer value rests greatly on a component that can be continually varied to match individual wants and needs.
4. Mix: Can use any of the above types, with the clear distinction that the components are so mixed together that they themselves become something different. The key factor in determining if you can take advantage of mix modularity is *recipe*. Anything with a recipe can be varied for varied markets, different locales and indeed for different individuals.
5. Bus: Uses a standard structure that can attach a number of different kind of components. Most difficult to comprehend. Key distinction of bus modularity is that a standardized structure allows variation in the type, number and location of modules that can plug into it. Key is the existence of a bus.
6. Sectional: Allows the configuration of any number of different types of components in arbitrary ways – as long as each component is connected to another at standard interfaces. An example of this concept is Lego. Key is to develop an interface that allows sections or objects of different types to interlock. This is often much easier to accomplish in service industries.

Anderson (1997) introduces two specific types of modularity that may enable mass-customization. First, virtual modularity, which does not limit modules to physical building blocks. Drawings of virtual modules could be combined and "assembled" in CAD (computer aided design) systems. Second, hidden modularity, which is a type of modularity that is hidden for the customer, who may prefer an integrated product – or at least the *appearance* of an integrated product. Products could be assembled from various choices of modules, but then be assembled in what appear to be integrated products and are sold as such, but with a high degree of modularity inside the "system". O'Grady (1999) follows the latter line of reasoning and introduces soft and hard modules. Especially the soft modules, such as financial services or software, are suitable to customize a product beyond the physical limits of the (hard) product.

Feitzinger & Lee (1997) argue that three organizational design principles form the basic building blocks of an effective mass-customization program:

- A product should be designed so it consists of independent modules that can be assembled in different forms of the product easily and inexpensively;
- Manufacturing processes should be designed so that they, too, consist of independent modules that can be moved or rearranged easily to support different distribution-network designs;

- The supply-network should be designed to provide two capabilities: ability to supply the basic product to the facilities performing the customization in a cost-effective manner and flexibility and responsiveness to take individual customers' orders and deliver the finished, customized goods quickly.

Although modularity and mass-customization are closely connected. one should note that modularity in itself is not the same as mass-customization. It is only one of many possible ways to achieve mass-customization. We already saw that modularity has several other benefits, while on the other hand, customer relationship management, advanced production and manufacturing lines, the use of information and communication technology and dedicated inbound and outbound logistics are other building blocks for effective mass-customization (Pine 1993, Piller 1998). In this dissertation we will consider the benefits of modularity in general, but focus in particular on the relationship between modularity (in three dimensions: product, process and supply chain) and mass-customization.

### 5.5.3 Disadvantages of modularity

Although most of the previously mentioned authors are very positive about the use of (product) modularity, it should not be seen as the panacea to all design problems. Pine (1993) indicates three potential drawbacks of modularity:

1. Performance of a product can always be optimized and its manufacturing costs lowered by reducing or eliminating modularity.
2. Customers may perceive some sets of modularized products as being overly similar.
3. Competitors can reverse-engineer modular design more easily than unique designs.

In line with disadvantage number one, Ulrich mentions that in general a product's performance can be enhanced by an integral (non-modular) architecture, at least when those performance characteristics are driven by the size, shape and mass of a product (Ulrich 1995). Fine (1998) also adds: 'arguments for the integral design are often largely technical or performance-based, whereas arguments for the modular tend to be based on business concerns such as cost and time to market.' In our opinion this a somewhat unclearly defined disadvantage.

Products, which are based on the same encompassing system (often called platforms) may only differ one or a few modules from each other. In this case, customers may indeed have difficulties in distinguishing them. This illustrates the second disadvantage.

Third, with a modular product design, competitors can more easily reverse-engineer (develop product specifications on the basis of an existing product in order to manufacture the product oneself) these designs while the components individually are more easy to copy than the entire product at once. The challenge for these competitors obviously will be to assemble all individual modules.

A fourth disadvantage is introduced by Baldwin & Clark (1997) who claim that modular systems are more difficult to design than comparable interconnected or integral systems, while the designers of modular systems must know a great deal about the inner workings of the overall product or process. Any problems with incomplete or imperfect modularization only appear when the modules come together and work poorly as an integrated whole. This is obviously a coordination issue. We saw earlier that a modular architecture is characterized by low levels of coordination, while the components are highly autonomous and able to self-organize. Furthermore, switching from an interconnected (or integral) to a modular design will have a dramatic impact not only on the overall system value but on the relative values of different components of the design as well. When the design of a particular component is poor, it can compromise the whole system (Baldwin & Clark 2000). The system's designers thus need to develop ways of testing the system before it is assembled and goes to market. It is very difficult to form or test hypotheses that address the contributions of individual elements to the whole, also called the "credit assignment problem" (Holland 1992). If the designers of a system lack a valid theory of how each component affects the performance of the whole, apparently every combination will appear equally good. Then, to find the *best* combination among all possibilities, the designers will have to measure the performance of every single combination against every other combination (Baldwin & Clark 2000). This is further complicated by the fact that in some systems (like supply chains or business networks) there is no central authority present (i.e. the system's designers), which is responsible for and can actually perform these tests.

All of these arguments illustrate the tension between choosing an integral or modular design and the need to find the right balance.

## *5.6 Research Framework*

All the previous discussions on modularity, integrality, customization, clockspeed, ICT and firm performance together should lead to one encompassing research framework that tries to describe and explain the relationships between all of these concepts. The research framework, or conceptual model, on modularity and mass-customization, looks as follows:

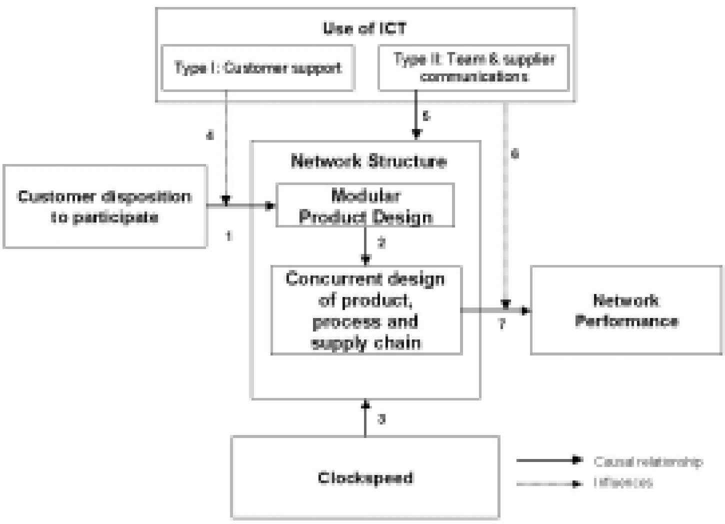



**Figure 5.3: Research framework**

The entire framework is both descriptive (offering a particular perspective on business networks and trying to understand their structure and performance) and prescriptive (indicating the desirability of certain relationships and dependencies). It is a dynamic model indicating that the (modular) network structure and its effectiveness may be contingent upon a number of other factors.

The model itself may thus be used to analyze business networks in order to understand and explain their use of modularity in combination with their performance. Performance in this respect refers to network effectiveness in general, i.e. the extent to which a network achieves the desired end (Jarillo 1988). In particular we focus on the advantages of modularity of which mass-customization is a strong representative. By means of the model we can thus investigate how mass-customizing networks of organizations use modularity and subsequently answer questions such as why they should increase or decrease the degree of modularity used or perhaps employ more or less ICT. Validation of the model should eventually help us in answering the research questions formulated at the beginning of this chapter.

Each of the defined (causal) relationships makes up one proposition, which will be described below.

P1 *The higher the customer's disposition to participate, the higher the degree of product modularity.*

With respect to proposition P1 the following can be mentioned. The more involved a customer can and wants to be in the design and assembly of the product, the more modular this product will need to be. More possible configurations will be needed to satisfy the diverging and heterogeneous demands. By employing modularity, heterogeneous customers can choose a configuration that more closely meets their preferences. Customer disposition to participate consists of heterogeneity of demand, as well as the willingness and ability of the customer to participate. It may be expected that customers only prefer a limited amount of involvement up to their own willingness and ability to participate in the design and assembly. Low willingness and ability from the side of the customer will decrease the need for a modular design. It will therefore be investigated 'how much' product modularity is desirable given the customer's disposition to cooperate in design. Pine (1993) already states 'variety in itself is not customization'. Suppliers must learn about the activities and requirements of their users (their willingness and ability) and how "much" of a customized product should be provided in the form of standard components or modules (von Hippel 1998). The degree of modularity should be such that customers do not consider products overly similar or otherwise insufficient (Huffman & Kahn 1998)[14]. Schilling introduces three hypotheses which are very similar to ours:

- The degree of difficulty customers face in assessing the quality and interaction of components will be negatively related with increasing inter-firm product modularity.
- The degree of difficulty customers face in assembling components will be negatively related with increasing inter-firm product modularity.

[14] From a design point-of-view a set of products exhibits high levels of commonality if many modules are shared (Robertson & Ulrich 1998).

- Customer heterogeneity in desired function or scale of product, will be positively related with increasing inter-firm product modularity.

P2 *The more modular a product design, the more modular process and supply chains will be designed as well.*

Fine (1998) states that product and supply chain architectures tend to be aligned along the integrality-modularity spectrum. That is, integral products tend to be developed and built by integral processes and supply chains, whereas modular products tend to be designed and built by modular processes and supply chains. They tend to be mutually reinforcing and conducive to each other. It is also stated that both products and processes should be considered simultaneously. For instance, Sanchez finds an analogy between product and process architecture, while the concept of Concurrent Engineering or Design for Manufacturability explicitly coordinates the design of products with the actual production system in the factory. The concurrency between processes and supply chains is further addressed by Feitzinger & Lee (1997) who state that manufacturing processes should be designed such that they, too, consist of independent modules that can be moved or rearranged easily to support different distribution-network designs.

P3 *The higher the clockspeed of an industry, the higher the need for a concurrent, modular design of the network will be.*

Higher clockspeed industries could be more profitable and suitable for modular architectures, with its diverging demands, short product life-cycles etc. Or, as Starr (1965) states: 'Industries with short life cycles will react earlier to possibilities for modular production'. Furthermore, high clockspeed industries require a better alignment between the three design constructs product, process and supply chain. That is, concurrent engineering of the three elements is far more essential in these industries. Synchronization with the evolution of the industry is more important when the industry evolves very quickly. Fine (1998:132) phrases it as such: "In the absence of time pressure, the penalties for working slowly and sequentially rather than concurrently are only mild. As the clockspeed of industry after industry has begun to heat up from the driver of global competition, the necessity of concurrency has struck home." Worren et al. (2000) come up with a similar hypothesis:

- Firms facing a more dynamic market context are more likely to employ modular product architectures.

Schilling (2000) also stresses the relation between market dynamism and modularity, hypothesized as:

- If there are pressures to increase or decrease the inter-firm modularity of a product system, the speed of technological change will increase the likelihood of such a migration.
- If there are pressures to increase or decrease the inter-firm modularity of a product system, competitive intensity will increase the likelihood of such a migration.

P4 *The higher the use of ICT customer support tools, the stronger the relation between customer disposition to participate and modular product designs will be.*

It is expected that with the increasing proliferation of ICT, the extensive use of Internet and E-commerce applications, customers will become more involved and better supported in designing their own products. This will subsequently increase the modularity of these products. For instance, interactive media can be used to allow customers to manage part of the product design themselves, learning relationships can be created through ICT and customers can gain access to design tools and delivery systems. These are type I ICT applications (based on Mendelson & Pillai 1998). Section 5.4.3 further describes the operationalization of ICT use and the division into two types.

P5 *The higher the use of ICT tools for team and supplier communications, the more concurrent the three modularity dimensions will be designed.*

Furthermore, information systems such as team communication applications and supplier EDI can be used to bring the modules together, coordinate their development and test their performance. Therefore, the higher the use of such systems (denoted as type II applications), the more modular a business network or system will be.

P6 *The higher the use of ICT, the more effective a concurrently designed interorganizational business network will be.*

Finally, given the degree of concurrent design of a network or supply chain (see proposition P2), the use of ICT can further increase the performance of such a network. E-mail, EDI with suppliers, confirmation of delivery and order processing, videoconferencing are all tools that could increase customer satisfaction, development costs, delivery times and so on.

P7 *A concurrent, modular design of products, processes and supply chains increases the performance of interorganizational business networks in general and a mass-customization strategy in particular.*

This proposition indicates the need for concurrent design of products, processes and supply chains. It is proposed that an interorganizational network will be more effective when the three architectural elements are designed concurrently, as opposed to separately or independently. Effectiveness, i.e. network performance, in general refers to the proposed advantages of modularity described by O'Grady (1999), which were summarized in section 5.5.1. In particular, we will investigate the benefits of three-dimensional modularity for mass-customization. Modularization is expected to be the most effective way to accomplish this. In other words we expect modularly designed networks, which are trying to mass-customize their customer offerings, to be more successful than those who do not.

## *5.7 Validation of the Research Framework*

The next step is to empirically validate the research framework. For this purpose, we first need to operationalize the different constructs of the framework. Operationalization means translating the constructs in applicable variables, which should be directly measurable in practice. This often is a very complex task where the validity of the translation process needs to be observed very carefully, to ensure that one is actually measuring what one wants to measure. The same difficulties hold for the proposed (causal) relationships between the constructs or variables. We will use operationalizations available in the literature when possible, however when they are lacking, we will use a more explorative approach. The latter means that we will need to formulate the variables ourselves, measure them in an empirical setting and adapt them when required.

As the first - explorative - effort in validating our research framework we will carry out a case study in the Dutch housing industry, where we focus on a housing project which has the objective of building mass-customized houses with a high degree of influence for the customer on the design of the house. This case study should help us in further examining our propositions, the operationalization of the constructs and improving the framework where necessary. The (methodological) reasons to carry out a case study first, instead of a more statistically comprehensive method, such as a survey, will be elaborated on in the next chapter.

# CHAPTER 6 CASE STUDY: MODULARITY IN A DUTCH HOUSING PROJECT

## *6.1 Introduction*

### 6.1.1 Customer influence in the Dutch housing industry

For many years the housing industry in the Netherlands has been a very traditionally organized industry with a low degree of industrialization (see e.g., Voordijk 1994, Bakker & Rapp 1998). Furthermore, the housing industry is strongly regulated; the national government has a great degree of involvement in the industry. A couple of years ago they came up with the idea of building numerous (approximately 60,000 houses per year until 2010) expansion suburbs, just outside city centers, which they called Vinex locations, to meet the growing demands for houses. These locations however, are largely criticized because of their low quality, minimal customer influence and inferior facilities, such as public transport, schools and cultural events.

Due to the low degree of industrialization and the many governmental regulations, the customer is paying a large amount of money - a house is for most people the largest spending in their life - for a product they have no real say in. Only during the last phase of a house building project does the customer become involved in choosing the colors of the tiles in the bathroom or he may select a kitchen from a showroom, in the best case. Obviously everyone can have his own 'dreamhouse' designed and built for himself, but this is a very costly affair, not within reach of most people. Therefore, the need for mass-customization of houses seems apparent in this industry. More and more, the housing industry is looking for ways to increase the influence of the customer on the design of their own house, without increasing the price too much and loosing the advantages of serial, project-wise, production.

In particular, an experimental housing project, called *Gewild Wonen*, which is carried out in a Dutch city called Almere is one of the first serious efforts in this direction. A literal English translation of *Gewild Wonen* would be Sought After Housing or Housing on Demand. We will however use the Dutch name or simply call it the *GW-project.* This project is one of the first steps the Dutch housing industry takes towards more customer-influence on a serial basis. It is an experiment to explore the organizational and technical difficulties belonging to such a mass-customization strategy. We have analyzed the *GW-project* to explore the validity of our research framework on modularity and mass-customization.

### 6.1.2 Explorative Case Study: *The GW-project* in Almere

To mark the occasion of the 25 year existence of the city of Almere in 2001, an exposition has taken place based on this theme. As mentioned above, the initiators named the exposition *Gewild Wonen*. The exposition was one of the first steps the Dutch housing industry took towards more customer-influence on a serial basis. It was considered an experiment according to the people behind the project, to explore the possibilities to accomplish this, both on an organizational as on a technical level. The experiment had two objectives:

- Individualization of quantity-produced housing
- The possibility of easy future alterations of the house

From a research point of view, this experimental project was a very valuable case study for our purposes for the following reasons. First, the (Dutch) building industry is an industry where (mass-)customization is still in an early stage. By studying the project we will be able to compare the developments in the building industry with more mature industries, such as the automotive and computer branch. Second, the way the project is set up (as an experiment) enables us to investigate the project in close detail and follow its progress from nearby. For a researcher this is a very interesting position. Third, we expect all variables of our research framework to be subject to change because of the character of the project, which is much different from other, regular building projects. This allows us to investigate the dynamic interactions between the variables of the framework. Summarizing, we are mainly interested in the use of modularity in this project and in a more general sense, in the use of modularity within the housing industry. To what extent do the organizations use modularity and why?

### 6.1.3 Research method

The research method used in this chapter is the case study. In chapter 2 we already discussed the case study in comparison with action research. Where the studies carried out in the air cargo industry merely had an action-research character, this time our study is a pure case study, as defined by Yin (1994), Eisenhardt (1989) and Lee (1989). One can distinguish two generic types of case studies: explorative and theory testing. The former has been extensively described by Eisenhardt (1989), the latter is discussed by Yin (1994) and Lee (1989). Whether a case study can or needs to be explorative or testing obviously depends on the status of the theory one is investigating. In our case, the theory we developed was still in its developing stage – not much earlier research could be found on the theory - therefore, an explorative case study was carried out (followed by further, statistical testing of the theory by means of a survey, which has been described in the next chapter). Before the exact protocol is discussed, we will elaborate further on the difference between explorative (theory developing) and theory testing case studies.

**Explorative, theory developing case studies**

An often-cited article about case study research in theory development studies is from Eisenhardt (1989). Using the work on qualitative methods from Miles and Huberman (1984), case study research (Yin 1994) and grounded theory building (Glaser & Strauss 1967), she provides an eight step road map to *building* theories from case studies, provided in table 6.1 below.

| Step | Activity | Reason |
|---|---|---|
| **Getting started** | Definition of research questions | Focuses efforts |
| | Possibly a priori constructs | Provides better grounding of construct measures |
| **Selecting cases** | Neither theory nor hypotheses | Retains theoretical flexibility |
| | Specified population | Constrains extraneous variation and sharpens external validity |

| | | |
|---|---|---|
| | Theoretical, not random, sampling | Focuses efforts on theoretically useful cases |
| **Crafting instruments and protocols** | Multiple data collection methods | Strengthens grounding of theory by triangulation of evidence |
| | Qualitative and quantitative data combined | Synergistic view of evidence |
| | Multiple investigators | Fosters divergent perspectives and strengthens grounding |
| **Entering the field** | Overlap data collection and analysis, including field notes | Speeds analyses and reveals helpful adjustments to data collection |
| | Flexible and opportunistic data collection methods | Allows investigators to take advantage of emergent themes and unique case features |
| **Analyzing data** | Within-case analysis | Gains familiarity with data and preliminary theory generation |
| | Cross-case pattern search using divergent techniques | Forces investigators to look beyond initial impressions and see evidence through multiple lenses |
| **Shaping hypotheses** | Iterative tabulation of evidence for each construct | Sharpens construct definition, validity and measurability |
| | Replication, not sampling, logic across cases | Confirms, extends and sharpens theory |
| | Search evidence for "why" behind relationships | Builds internal validity |
| **Enfolding literature** | Comparison with conflicting literature | Builds internal validity, raises theoretical level and sharpens construct definitions |
| | Comparison with similar literature | Sharpens generalizability, improves construct definition and raises theoretical level |
| **Reaching closure** | Theoretical saturation when possible | Ends process when marginal improvement becomes small |

**Table 6.1: Process of building theory from case study research (Eisenhardt 1989)**

During our study, we have tried to follow these eight steps as close as possible.

### Theory testing case studies

In some stages, a theory testing case study is similar to a more explorative one. Some features of the process, such as problem definition and construct validation, are similar to hypothesis-testing research. Others, such as within-case analysis and replication logic, are unique to the inductive, case-oriented process (Eisenhardt 1989). Testing a theory using one or multiple case studies often involves a number of methodological problems. Lee (1989) mentions four criteria that should be met when executing a theory-testing case study. They are:

1. Making controlled observations
2. Making controlled deductions
3. Allowing for replicability
4. Allowing for generalizability

Especially in a single case study these four criteria may be hard to meet. One needs to be able to "control for" potentially confounding influences of all other factors - next to the factors under consideration. Often, the researcher must deal with qualitative data and verbally stated propositions, which make it difficult to make controlled deductions. Furthermore, it is very unlikely that some set of events may ever be replicated, with exactly the same configuration of individuals, groups, social structures etc.. The non-replicability of the same observations would clearly hinder verification of the results by other independent researchers. Finally, single case findings may be subject to criticism and vulnerable to charges that these findings cannot be extended to other settings. The generalizability of the results may therefore be limited. Lee (1989) introduces a number of responses to these problems. These are:

1. Make controlled observations by utilizing *natural controls*
2. Use the rules of *formal logic* to make controlled deductions
3. Work with new predictions, using observations *different* from the ones made by the original researcher. This will make the case study's findings replicable
4. Generalize the theory to other sets of empirical circumstances on the basis of actually being confirmed by additional case studies that test it against those other sets of empirical circumstances.

### 6.1.4 Research protocol

As mentioned above, it was decided, based on the status of the theory under investigation, to carry out an explorative case study. A triangular approach has been followed in the *GW-project* case study. In the preparation phase of the project, semi-structured interviews with the stakeholders (architects, property developers, builders, public housing corporations, estate agents, employees of the city of Almere etc.) were held to gain more background knowledge about the project and the viewpoints and experiences of the participants. The content of each of the questionnaires was appropriated for the participant being interviewed, either focusing on the design phase or focusing on (the preparation of) the execution phase. Questions about the design phase were mainly posed to the architects and property developers. Questions about the execution phase were posed to the builders and again, the developers. The questionnaires can be found in appendices 4 and 5.

After most of the stakeholders were interviewed once, we were able to come up with a global impression of all projects, the problems they were facing and the solutions they had found. At the end of the sales period, the stakeholders were approached once again and they were asked to fill in a more structured survey. This enabled us to further validate our initial conclusions and to confront the stakeholders with each other's remarks. This questionnaire can be found in appendix 6. After the sales process an investigation was held among the buyers of the houses to assess their perceptions and experiences in the project. The opinions of the customers were used to obtain an impression of the success of the individual projects within the *GW-project*. This questionnaire can be found in appendix 7.

In summary, the following analysis steps were taken:

1. Analyze several documents and studies about the structure of the housing industry, similar projects in the Netherlands and other countries and contemporary developments within the industry.
2. Explorative semi-structured questionnaire with two purposes: getting acknowledged with the housing industry and exploring the validity of the constructs. The questionnaire was executed at the beginning of the experiment, when the participants also had many unanswered questions about the project and its implications for their own business. Questions were answered verbally in a face-to-face interview with the researcher. In total over 30 interviews were held in a period of approximately 4 months. See appendices 4 and 5 for the set up of the questionnaires.

3. Get feedback from the participants on early findings to further refine the framework by means of a presentation of the early results to the participants.
4. Testing questionnaire: executed after the majority of the houses were sold to the customers and the stakeholders knew more about the choices made by the customers, the cooperation with other parties in the project etc (appendix 6).
5. Customer investigation: together with the city of Almere a customer investigation was undertaken to analyze the experiences, motivations and degree of satisfaction of the buyers of the house. The survey itself can be found in appendix 7.

The complete research protocol has been depicted in table 6.2 on the basis of the eight process steps defined by Eisenhardt (1989).

| Step | Activity | Actual choices |
|---|---|---|
| **Getting started** | Definition of research questions and a priori constructs | See section 5.1.2 and research framework of section 5.6 |
| **Selecting cases** | Specified population and theoretical sampling: | *The GW-project* |
| **Crafting instruments and protocols** | Multiple data collection methods, combining quantitative and qualitative data | Interviews, surveys and additional documentation |
| **Entering the field** | Overlap data collection and analysis, combined with flexible and opportunistic data collection methods | Questionnaires were adjusted - where necessary - on the basis of answers of early respondents. Customer survey was added in a later phase. |
| **Analyzing data** | Within-case analysis, combined with cross-case patterns | Each sub-project within *The GW-project* was analyzed individually and compared with the other sub-projects |
| **Shaping hypotheses** | Tabulation of evidence and search evidence for "why" | Cross-case table and evaluation survey |
| **Enfolding literature** | Comparison with literature | Reflection on literature overview of chapter 5 |
| **Reaching closure** | Theoretical saturation enforced by end of project | Focus on preparation and design phase of project; execution phase omitted |

**Table 6.2: Research protocol (based on Eisenhardt 1989)**

### 6.1.5 Chapter overview

Section 6.2 contains a brief description of the backgrounds of *The GW-project*, followed by an overview of the structure of the Dutch building industry (section 6.3). In the subsequent sections (6.4 to 6.11) we will each time discuss one of the constructs of our research framework. We will further elaborate on the current degree of customer influence in the building industry, the subsequent phases in a building project, the use of modular coordination, several building methods and possible organizational models within the industry. All of these housing-specific issues will be linked to our research framework. In section 6.12 the validity of our propositions will be discussed followed by a number of conclusions that may be drawn from the case study. These conclusions are used to validate and further refine the research framework, which is subsequently used for the multi-industry survey. The results of this survey are discussed in chapter 7.

## *6.2 The GW-project: Description*

### 6.2.1 Background: Spontaneous Housing

To explore the organizational and technical difficulties belonging to more mass-customization in the housing industry, the city of Almere, a 25-year-old town in one of the Dutch polders, decided to initiate an experimental project in early 1999: *Gewild Wonen*. *The GW-project* originates from the ideas of Carel Weeber, a professor in architecture and a well-known architect in the Netherlands. In 1997 he introduced the concept of '*Het Wilde Wonen*' (in English: Building Wildly or Spontaneous Housing). *Het Wilde Wonen* disputes the governmental influence on and interference with the architecture and urban design in the Netherlands. It resists the rigid way of urban planning, the uniformity and the lack of variation within the housing industry. *Het Wilde Wonen* aims at an informal approach with possibilities for unexpected and unplanned designs. Houses should be built in lower densities, avoiding the compact housing areas dedicated by the government. These areas are called 'Vinex locations', named after the fourth governmental Note Spatial Design. The Vinex locations merely consist of fairly identical row houses, with a very low degree of customer influence on the design of the house. Choices are limited to dormers, bays, closets, tiles and sometimes kitchens and toilets. Weeber argues for more informal types of living, where no central direction or control is present. The customer should get freedom in choosing the shape, the building method and the exterior of the house.

While the demand for houses is no longer determined by corporations or property developers, building companies need to reorganize their processes to be ready for more customer-oriented development and building, according to Weeber. This concerns ongoing research of consumer requirements and a change in the way houses are sold. Design assignments no longer are given for entire houses only, but also for parts. Most likely, during the execution phase fixed suppliers take care of the just-in-time delivery of elements, enabling production-on-demand. This should serve two purposes. First, builders no longer have to interfere with the architect, but can standardize their production and products. Second, occupants can design their own house to a large extent.

### 6.2.2 Plan of Approach

The city of Almere decided to initiate an exposition around the theme of *Het Wilde Wonen*. However, the 'wildness' of the project could not be as great as Weeber originally had in mind. Almere felt the market (both the customer as the supplier side) was not ready for this. It was decided to invite a number of professional property developers to come up with architectural designs, based on the theme. Therefore, because there is still no direct interference of the buyer with the architect and builder, the project was renamed into *Gewild Wonen*[15]. The project in its entirety had to display the image of housing in the 21st century according to the initiators. The objective was to design and build houses with such a variety that on the one hand no house would look the same, while on the other hand the advantages of project-wise building were preserved.

The initiative of the project was taken in early 1999. Almere invited 11 property developers, who acted as order placers, to participate in the projects. Later on, three public

[15] The transition from *Wild* to *Gewild* is both in meaning as linguistic a nice find.

housing corporations were invited to participate as well, just as Carel Weeber himself. Each property developer was asked to invite two architects, which they could select from a list offered by the city of Almere or search for themselves, to come up with a house design. Subsequently, the city of Almere chose, based on a number of criteria (see section 7.2), one of the two designs of each of the property developers. The selection process took place in June 1999. The corporations and Carel Weeber were released from this contest, due to their later entrance in the project. They were allowed to come up with only one design.

The initiators of the project followed the following plan of approach. First, the fifteen architects received the assignment to design just a base, a core, of the house with the necessary utilitarian and sanitary provisions. This design should not be a complete house, but just the start of a house. Subsequently, the architect was supposed to deliver a catalogue of components to complete the house. Using the components the house could be assembled, in much the same way a car is assembled. The style, material and size had to be determined by the (future) owner of the house. The components chosen from the catalogue of styles could be assembled on the building site. The exact position of house on the plot should be a free choice, as long as the privacy of the adjoining dwellings was not hampered. The appearance of the houses was bounded by only a minimum of rules. Only the building height was limited to three floors. Flat roofs or topped roofs, both were allowed. Furthermore, the shape of the roof was free, as well as its slope and its direction. Complete freedom also existed with respect to the materials and the colors. The house could be located anywhere on the plot, directly accessible from the street or hidden away somewhere deep down. The houses could be built as detached houses, semi-detached or three in a row at most. Most houses were low-rise houses, complemented with five urban villas along the central canal. Four of these villas were built with seven floors (plus a penthouse). The fifth urban villa could be built higher than the other ones, because of its different position in the neighborhood, on a crossroad between two canals.

The exposition was located in a part of Almere-Buiten, the Eilandenbuurt (Island neighborhood) – see figure 6.1. The total number of houses to be built is approximately 600. The area in which the exposition took place consisted of a dry and a wet part. The wet part has been developed as a series of islands. The dry part consisted of one large island surrounded by canals. The exposition took place from 13 till 23 September 2001.

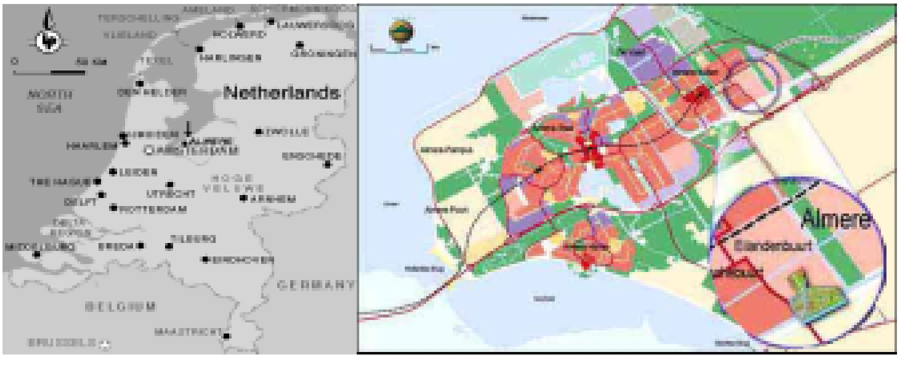



**Figure 6.1: Location of *The GW-project***

### 6.2.4 Description of fifteen sub-projects

As already mentioned, there are 15 different sub-projects within the entire *GW-project*. We will briefly discuss these sub-projects below.

<table>
<tr><th>Name project</th><th>Architect</th><th>Order placer</th><th>Builder</th><th>Number of houses</th></tr>
<tr><td>1. The Growing House</td><td>Laura Weeber</td><td>ABB Bouw</td><td>ABB Bouw</td><td>21 low-rise</td></tr>
<tr><td colspan="5">The focus in this design merely lies on the extensibility of each house; each house needs to be able to ‘grow’. The houses are on two sides (front and back), in linear direction, in segments extensible. The segments are built by using steal rafters and they decrease in height after each extension. Starting point for construction and materialization was the application of a non-specific, and already existing, traditional building method, because the designers argued that it also needed to be possible to extend the house months or years after the delivery. In this way occupants can easily find and buy additional building materials.</td></tr>
<tr><td>2. The Reflection</td><td>BDG</td><td>Verwelius</td><td>Verwelius</td><td>30 low-rise, 21 high-rise</td></tr>
<tr><td colspan="5">The plots for the low-rise houses have different sizes; they differ in width. Customers can choose for plots of 9 or 11 meters wide. On the smaller plots only detached-connected houses are possible. The 11-meter wide plots also allow for fully detached houses. Customer can subsequently choose the number of layers and shape of the roof. The garage part contains all standard facilities, such as the toilet and the meter cupboard. This makes the living part freely designable by the buyer. This includes the location of the kitchen, stairs, and walls. The façade may be chosen, just as the façade material. Finally, the buyer may select numerous accessories, such as a verandah, a bow window or an awning or he may visit a showroom to pick his desired kitchen and sanitary facilities.<br>The layout of the eight-story apartment building is almost completely predetermined by the architect. It contains five types of apartments, three apartments on each floor, where the three penthouses contain two stories.</td></tr>
<tr><td>3. Living in a block-house</td><td>Bart Duvekot</td><td>Rehorst</td><td>Rehorst</td><td>36 low-rise</td></tr>
<tr><td colspan="5">Buyers can become order placer by choosing a number of blocks and grouping these blocks according to their own requirements. On a plot six foundation blocks of 4x4 meters are installed, in a 2 by 3 grid. Each house is limited to two floors, so each house can maximally consist of twelve blocks. Buyers can make a selection out of these twelve blocks and thus configure their own ‘block-house’. One side is always on the border of the plot, making sure sufficient privacy remains for the occupants. One of the blocks contains the entrance, the toilet, the stairs, the storage room and the installations. Furthermore, on the second floor a standard block is installed with bathroom, stairs and installations. Both blocks are compulsory in each house.</td></tr>
<tr><td>4. Do you want the main part?</td><td>Buro 5 Maastricht</td><td>Hopman</td><td>Hopman</td><td>24 low-rise, 28 high-rise</td></tr>
<tr><td colspan="5">Hopman and Buro 5 developed 24 villas and 28 apartments, which they called ‘direction-houses’. The villas posses several possibilities to extend the basic house on the ground floor, the first floor or by adding a second floor. Façades are also free to choose, out of a number of fixed models. The apartments offer freedom in layout and finishing. The basic apartment only contains an entrance, a staircase and piping systems as fixed elements. By using a CD-ROM the customer will be confronted with a questionnaire. Data on the buyer, the type of living and the budget, will be complemented with specific requirements concerning areas, materials and color settings. Eventually this should lead to the desired house. Subsequently, the exact plot and the location of the house on the plot are determined.</td></tr>
<tr><td>5. Pioneers in the Polder</td><td>Colijn & Feekes</td><td>GBV Zondag</td><td>GBV Zondag</td><td>32 low-rise, 1 high-rise building</td></tr>
<tr><td colspan="5">The developers clearly distinguish between the responsibilities for the architect (building technique and unity in total image) and the buyer (interior and accessories). The house itself is assembled from several design modules, sized 3.30mx3,30m. A few function specific modules have been developed, for sanitary, entrance and the stairs. The other modules are volume modules. The architect formulated a number of rules for the customer to ensure privacy, sunshine and unity in total image; for the rest the buyer is completely free to design his house. This includes shape of the house, layout of the rooms, type of roof, colors, materials and the front door.</td></tr>
<tr><td>6. Personal house & garden style</td><td>FARO / Theo Verburg</td><td>Bemog</td><td>Nijhuis / Moes</td><td>36 low-rise, 21 high-rise</td></tr>
</table>

<table>
<tr><td colspan="5">This project is the only project where one order placer deals with two architects and two builders. The low-rise buildings are designed by FARO and built by Nijhuis. The high-rise apartments are designed by Theo Verburg and built by Moes. Where in the other project one winner was pointed out for the entire sub-project, this project had two winners, each responsible for one half. The plan designed by FARO offers freedom of choice in several stages. First, the type of plot is chosen. The uniqueness of this design is the large variety in shapes and sizes of the plots. After the plot is chosen, the size of the ground floor is determined, followed by the exact position of the house on the plot. Then, the buyers can compose the façade and decide upon the number of floors. Finally, the color of the house is chosen. The coherence between all houses is created by a heavy, romantic garden-style wall.<br>The apartment building consists of 21 apartments in different shapes. The shapes are predetermined by the architect, divided in 4 different types and one penthouse. The façades of the apartments consist of different materials. The floor plans are flexible and to a large extent free to choose by the buyer.</td></tr>
<tr><td>7. Multiple Choice</td><td>Architekten Cie</td><td>Koopmans</td><td>Koopmans</td><td>18 low-rise, 1 high-rise building</td></tr>
<tr><td colspan="5">All houses fit within a so-called envelope, which makes sure that all houses fit within the sizes such that there is not too much interference with the adjoining houses. Within this envelope a carcass is cut out, based on the personal requirements of the buyers. In theory, the entire plot can be filled, but only when the envelope is respected. A questionnaire is used to determine the size of the carcass within the envelope. Items within this questionnaire are: position of the car, the garden, the staircase, the distribution of the rooms, the spatial add-ons (such as a bow window or a loggia) and accessories (terrace, carport or a wintergarden).<br>The apartment building consists of 7 types of apartments. Again, standard modules of different sizes make up the size of the apartments. The buyers however, have no say in the composition of the modules into apartments; the composition and location in the building are predetermined by the developers. Buyers select the apartment they prefer out of the available types, which vary in number of floors and floor plans.</td></tr>
<tr><td>8. Personal Housing</td><td>Carel Weeber</td><td>ERA</td><td>ERA</td><td>7 low-rise</td></tr>
<tr><td colspan="5">ERA and Carel Weeber were only invited to participate in a later stage of the project; initially they were not invited. For this reason, only seven houses were available. The design is based on the American model, according to the architect. ERA always uses choice packages in projects such as this. This time a light building technique is chosen, where customer can decide upon the type of house, the architecture, the size and the finishing of interior and exterior.</td></tr>
<tr><td>9. All hands on deck</td><td>Verheijen Verkoren de Haan</td><td>Proper Stok</td><td></td><td>47 low-rise</td></tr>
<tr><td colspan="5">This sub-project is in itself once again divided in three different sub-projects. These sub-projects vary in the amount of customer participation and involvement. The first, with the least influence, has been designed according to a fixed measurement system. The core module already exists, but the interior is fully free to choose, e.g. innerwalls, doors, bathrooms, kitchens, extensions, balconies and piers. The second only consist of 15 carcasses: two building walls, a roof and a meter cupboard. The actual house is fully designed and built by the buyer. The building walls are however equipped with several holes, to place a floor at every level desired. The roof has this construction as well. The third, with the most freedom for personal expression, is a floating concrete boat carcass. This is the foundation for the future house. It contains a standard starting tower, where people can live in during the building process. For the rest, people can fully build their own ‘dreamboat’.</td></tr>
<tr><td>10. Choosing creatively, living recreatively</td><td>Claus & Kaan</td><td>NCB</td><td>Wilma</td><td>40 low-rise</td></tr>
<tr><td colspan="5">Buyers can choose out of five basic variants. Approximately one-third of the house is therefore fixed, the rest is free to choose for the occupant. This includes the roof, a possible garage and the location of the kitchen. The five basic variants all have fixed floor plans, based on a certain predetermined style: adventurous, serenity, family, atelier or hospitable.</td></tr>
<tr><td>11. Free-style living</td><td>M.I.N. 2</td><td>Credo</td><td>Te Pas</td><td>32 low-rise</td></tr>
<tr><td colspan="5">This design is characterized by a large freedom for the buyer. A fully isolated peel, a so-called loft, consisting of wood, rafters and stone is the starting point. The infill subsequently takes place with materials the customer selects, in deliberation with the architect and contractor. The rafters enable relatively easy infill by the customer. In this way, it is not a matter of choosing from a number of fixed options, but really building your own house.</td></tr>
<tr><td>12. The Islands: Flexible watervillas</td><td>UN Studio / Ben van Berkel</td><td>Visser</td><td>Visser</td><td>49 low-rise</td></tr>
</table>

<table>
<tr><td colspan="5">Two types of villas are designed: rivervillas and islandvillas. Both start from a basic module system (several modules attached to each other), where the buyer can choose to add several extra modules, such as a top-room, a penthouse, a balcony or a tower. All houses are situated near the water. The carcass module in its basic stage offers the buyer the opportunity to arrange its own plan lay out. It also guarantees a minimum amount of square meters for each house. The optional package allows extensions to the house. These are constructively prefabricated steel elements. The hard-core selection of bathroom and kitchen is decisive for the further organization of the house.</td></tr>
<tr><td>13. Slimfit rental houses</td><td>SVP</td><td>Goede Stede</td><td>VDM</td><td>25 low-rise</td></tr>
<tr><td colspan="5">This project only concerns rental houses, while the order placer is a housing corporation. First, buyers can decide upon the size of their house, i.e. the number of floors, the layout and the number of square meters of the rooms. Second, buyers can influence the exterior of the house, i.e. the window layout on the front and back side. Third, buyers may indicate whether they require certain façade elements, such as a balcony, roof chapel or a door awning. To ensure a certain unity in the designs, one only offers a fixed set of building elements of windows, doors, walls and roofs. The houses are built using a woodframe building method, which allows future adaptation of the house in a relatively easy way. Special about this plan is that all houses are rowhouses, so no detached or semi-detached houses are built.</td></tr>
<tr><td>14. Living as only you would like</td><td>BBHD</td><td>WVA</td><td>Trebbe</td><td>24 low-rise</td></tr>
<tr><td colspan="5">This project concerns two housing blocks. The first is destined for less abled, seniors, starters, families, living groups and large families; in other words a differentiated audience. The houses are constructed from so-called basic modules of 30 square meters each. These modules can be combined into a complete house. The common elements, present in all houses, are the house separating constructions and the piping system. Each customer selects the number of basic modules and type of facilities he desires. Subsequently, the architect tries to combine all these demands and requirements and fit them together as some kind of jigsaw puzzle. The layout of each house is later on determined by the buyer himself, except for the location of the stairs and the piping system. The other housing block in the sub-project does not possess the 'jigsaw puzzle' structure. The architect and the order placer predetermine the location and size of the houses.</td></tr>
<tr><td>15. The kettlehouse</td><td>M. Rohmer</td><td>GSA</td><td></td><td>18 low-rise</td></tr>
<tr><td colspan="5">These houses consist of a kettlehouse and a shanty. The kettlehouse is the same for each home, the shanty may have different lengths and widths, partly depending on the size of the plot. In the kettlehouse there are stairs, corridors, sanitary provisions, storage room, installations and possibly a kitchen. Within the shanty the buyer can place floors and inner wands, thus designing his preferred layout.</td></tr>
</table>

**Table 6.3: Description of all 15 sub-projects of the *GW-project***

## *6.3 Building industry structure*

In this section we will describe - in general terms - the structure of the building industry in the Netherlands. Such a description is necessary to better understand the set up of the *Gewild Wonen* network and the reasoning behind certain choices made by the participants. It will also help us in analyzing the case for the purpose of the research framework formulated in the previous chapter.

The building industry is a complex network of actors where goods and information are exchanged between numerous parties. The organizational structure of the traditional building process is characterized by a relatively large number of independent sub-contractors and specialists, who together make up a temporary network for the duration of a building project. These organizations often differ a lot with respect to their size, market conditions and culture. Because of the often unique, one-time and complex character of a building project, for each project the order placer assigns separate unique contracts with a large number of different, autonomous companies. For each project an entirely new process structure is set up with new designing and executing participants. This network structure often leads to a strong focus on prices and costs, which could hamper efficiency.

Over the years, building organizations have merely been looking for efficiency, as opposed to innovation or customization. This led to a relatively traditional and uniform network culture, with many informal relationships and historically embedded relationships. Many developers and builders merged into large corporations. Architects mostly remained independent. Developers focused merely on product and project development, where architects added value by taking care of the esthetics and image of the design. The merging of developers and building companies was partly due to the increased customization trend, but mostly because of commercial reasons. Most organizations in the building industry are fairly small. The largest developer builds approximately 7000 houses a year, just as the largest builder, which is less than 7% of the total market. In the supplying industry, these percentages are much higher. It is not unusual that one organization has a market of around 30-40% percent.

The following figure depicts the stakeholders involved in a regular building project.

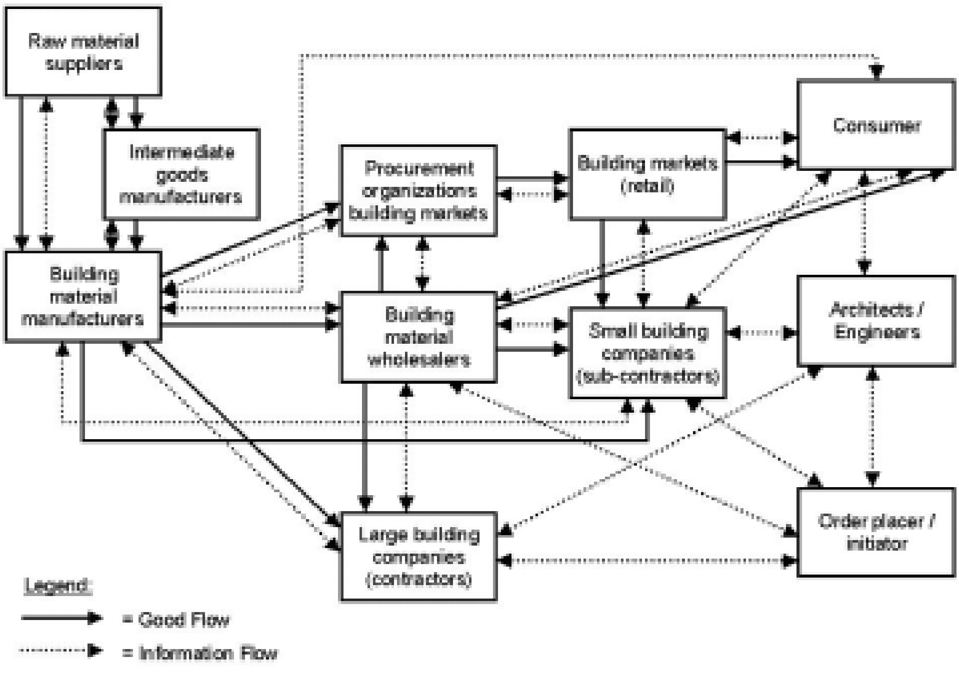



**Figure 6.2: Structure of a typical building network**
**(from seminar "E-commerce in the building industry", April 2000)**

One can see that a regular building network involves numerous parties. In the case of a housing project, such as the *GW-project*, an additional party is involved. This is the estate agent, which often takes care of the customer contact. A broker acts as intermediary between the order placers, the architects and the buyers/consumers. Below, the different relations within the network are described in more detail (based on Stroeken 1994, Voordijk 1994 and proceedings from the conference on E-commerce in the building industry – April 2000).

The raw material supplier supplies raw materials from, e.g., mining and lumber industry, to manufacturers and producers of intermediate goods or finished building materials. The relation between these organizations is often based on long-term agreements, with only a low frequency of information-exchange.

Frequent information exchange and a substantial amount of standard products characterize the relation between manufacturers and wholesale organizations. The wholesaler has a powerful position within the network because its wide variety in products makes it fairly independent of the, often highly specialized, manufacturers. The wholesaler is especially dedicated to logistic services and tries to be an intermediary between its own customers (the building companies) and the manufacturers. Customers of the wholesalers can choose from a large assortment of products from numerous manufacturers.

The relation between manufacturer and contractor often deals with the supply of standard products, such as prefabricated concrete elements and concrete armoring. This means that hardly any intensive interaction is required. In fact, all products could be directly distributed, but the wholesaler often offers additional service, which leads to more frequent contact.

In the relation between wholesalers and (large) building companies intensive interaction takes place where both parties more or less have equal power positions. Some of the building companies, such as NBM-Amstelland, have grown so large that they have become active in the entire building network. They participate in or own many nodes in the network. With respect to the wholesaler and smaller building companies the relation is characterized by less intensive interaction and a powerful position for the wholesaler.

The relationship between procurement organizations and building markets mostly takes place within a large building market corporation (such as Gamma, Karwei, Praxis or Formido). Almost 100% of communication is done through EDI (see section 6.9.4) and the procurement organizations more or less function as wholesaler for the building markets.

Finally, the relation between the small contractors (and end-customers) and the building markets can be described as incidental and irregular. Especially end-customers only seldomly engage in building activities, either do-it-yourself work or by hiring a contractor for some errand. The building market in this respect functions as a wholesaler and offers many of the same services to customers as it does to small contractors.

Finally, architects and engineers maintain relationships with contractors and order placers. The relation with the order placer is often only temporary – for the duration of the project – and based on personal conversations and documents, such as a Program of Requirements.

## *6.4 Customer disposition to participate*

### 6.4.1 Introduction

In this section and the following ones the research framework of chapter 5 is analyzed in the house building industry in general and the *GW-project* in particular. The framework is shown once again in figure 6.3.

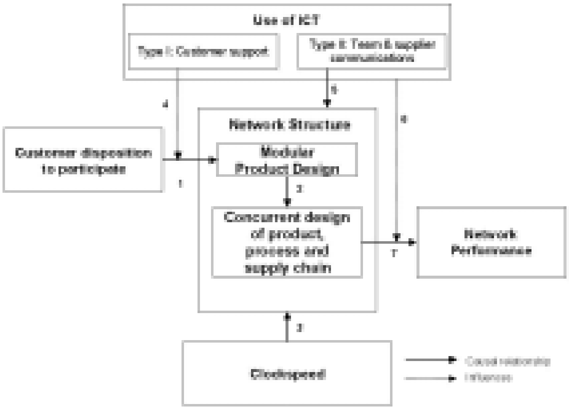



**Figure 6.3: Research Framework**

As mentioned in section 2.4.3, the deduction phase consists of the derivation of specific consequences from the hypotheses, in the form of testable predictions. This is exactly what we will try to do in this section. We need to translate all the constructs and accompanying variables into workable items and definitions to be used in the *Gewild Wonen* case. To do this, we will use several articles and publications about the house building industry. Eventually, this operationalization process leads (or should at least lead) to a number of testable predictions. For instance, in previous chapter it was mentioned that standardization of process (and supply chain) interfaces proved to be a somewhat difficult concept. The case study will be used to shed more light on this problem. These predictions will indeed be tested initially in the *GW*-case, although the accent mainly lies on the operationalization of the constructs. This operationalization, together with the preliminary test-results, can then be used in a broader test environment in order to try to statistically test our model. If in any case, the operationalization or the preliminary test of the hypotheses indicates that a change needs to be made to the model, this will obviously be done first before the testing phase is entered. The analysis will start with a discussion on customization in the housing industry.

### 6.4.2 Self-building and order placing

Since the beginning of the 80's the property developer has become the main order placer in the Dutch house building industry. Formerly, 'house corporations' functioned as professional order placers. The professional order placers are frequently involved in building projects and are experienced with the roles played by the building partners in the organizational model. Professional order placers could be own lodgers (such as banks, governmental organizations or libraries), investors, social house builders or property developers. The other type of order placer is the incidental order placer, who only places an order once in every five years at most. These order placers in general, have little knowledge about the fulfillment of a building project. They need to insource the required knowledge from somewhere to make their project successful. Obviously, people need good guidance during this process.

Over the last couple of years, private, incidental order placementship or self-building is strongly gaining ground[16]. It can be defined as 'building and developing houses in cooperation with the customer, where the customer may influence the architecture, the volume and lay-out of the house (within his own financial constraints)'. Many different types of self-building exist in practice. RIGO, a Dutch research and consultancy firm, analyzed the current status of private order placementship in the Netherlands (Keers et al. 1999). They came up with a so-called self-building scale, varying from traditional self-building to consumer-oriented property development. In traditional self-building, the influence of the buyer is the highest, while this influence is lowest for consumer-oriented property development. Even lower in this decreasing scale of customer-influence, we find regular housing projects. These projects bear no significant influence of the buyer on the design of the house and therefore, cannot be considered self-building projects. However, due to their low variation in house designs, they can often be executed relatively cheap and fast.

| Self-building type | Explanation | Features |
|---|---|---|
| **Traditional self-building** | The private person buys a plot and develops the house, possibly in cooperation with an architect and/or contractor. | - Requires lot of knowledge and experience<br>- Lot of risk<br>- Large variety in designs<br>- Often expensive |
| **Collective order placementship** | A group of private persons buys a plot and develops in mutual deliberation, with the help of an architect, an assistant and a contractor, a complex of rowhouses or apartments in the buying sector. | - Reduction of risk<br>- Good coordination possible<br>- Often cheap |
| **System building** | The private person develops the house together with a system builder, which is subsequently composed out of standardized components (prefab on component-level). | - Low risk<br>- Variety in designs<br>- Can be cheap |
| **Catalogue building** | The private person searches in a catalogue the required house or composes the house with the help of examples. | - Low risk<br>- Less variety in designs<br>- Can be cheap |
| **Consumer-oriented property development** | Property developer buys the plots, designs and builds the houses. The consumer can choose between different variations in fronts, color setting, use of material and the size of the house. There are also possibilities to determine the layout. | - Low risk<br>- Can be done on large scale, causing better coordination and economies of scale<br>- Most likely feasible in lower price classes |

**Table 6.4: Different types of self-building and their features (Keers et al. 1999)**

[16] The percentage of self-building in the annual production of houses has, since 1983, slightly increased from 12% to approx. 17% in 1998. The Dutch government wants this percentage to be 33% in 2005. A large variation can be found in this percentage depending on the exact location in the Netherlands. Urban, highly dense areas only reach 6% self-building, where rural areas already consist of 30% self-building. The newly built Vinex locations also score very low on this scale: 7% (Keers et al. 2000: RIGO report).

A special place is reserved for customer-oriented property development. This is a fairly new development of which the *GW-project* is the main representative. It is introduced as a new, intermediate form between the existing models of self-building, where the advantages of the other types (both high customer influence as well as low costs and higher efficiency) are preserved.

Summarizing, we see that operationalization and determining the degree of 'customer disposition to participate' is a little complicated in the housing industry. In most housing projects, the end-customer is hardly involved in the development of a house. Professional property developers more or less have taken over the role of the customer and decide what to build or not. Only at the end, when the house is almost completely designed and developed, does the customer come in and can decide about details and accessories. This means that currently, the heterogeneity of demand is quite low; the total number of property developers is only a fraction of the total number of customers and therefore, we may expect less variation in demand as well. On the other hand, the ability of a professional order placer is quite high; such an organization knows its way through the building industry and also has knowledge of technical design issues. The actual end-customer, the buyer of the house – probably has little ability and expertise in this respect. Finally, the willingness to participate in house design is expected to be higher for a private person than for a professional order placer. The latter does not have to live in the house itself, the former does. On the other hand, the customer may not be very eager to participate in the design and development when the financial risks are too high. These risks of realizing housing projects have to do with the (uncertainty of the) height of the investment costs associated with such a project and the ease of transferring these risks to other parties.

Still, we may expect, with more and more self-building projects, that the customer's disposition to participate will increase as well and as a consequence, based on our framework, the modularity of products. The two things however, that need to be 'controlled' for, are customer ability to participate (involving less-experienced buyers in the design process) and customer willingness (higher risks involved with self-building). Table 6.5 summarizes these findings, just as possible consequences of these changes.

| | Professional property developer | Private person | Consequence |
|---|---|---|---|
| **Heterogeneity of demand** | Low | High | More product-variation -> more modularity? |
| **Ability** | High | Low | Customers need to be supported |
| **Willingness** | Low | High | More product-variation, only when risks are covered |

**Table 6.5: The impact of more self-building on customization sensitivity**

### 6.4.3 Customer disposition to participate in the *GW- project*

The majority of the stakeholders in *Gewild Wonen* expected a low level of expertise on the side of the buyer of the house. In one of the sub-projects - *Living as only you would like* - the executioners explicitly tried to deal with this beforehand and designed a short questionnaire to obtain an impression of the ability and willingness of the customer to be involved in the design process. The corporation - WVA - had its potential buyers answer four questions:

- I am quite sure about how I want to live
- I think my requirements are feasible, both technically as financially
- I think the Island-area in Almere is an attractive area to live in
- I can and want to move in the Fall of 2001

Only when all four questions were answered affirmatively were people invited to participate in *Gewild Wonen*. If people sometimes needed to confess ‘no’, then they were urged to search in the actual house offerings of the corporation. In other words the WVA tested the willingness and (financial and technical) ability of their customers. Both factors should be sufficiently high; otherwise participation in the project was not useful. In this manner, the WVA ensured a sufficiently high level of ability and willingness on the side of the customer.

Still, the organizations realized that their buyers would need support during the design process. It was expected that the majority of the buyers would have little knowledge about house design and architecture. Therefore, much attention was paid to supporting the customers during this choice and selection process. Partly, this was done by using a number of ICT applications, which are described in section 6.9. Furthermore, a number of sub-projects used scale models to visualize the future house. Finally, use was made of questionnaires that enumerated the different options the buyer could choose from. Items within these questionnaires included: position of the car, the garden, the staircase, the layout and distribution of the different house areas, the spatial add-ons (such as a bow window or a loggia) and accessories (terrace, carport or a wintergarden). The following figure depicts such a questionnaire (in Dutch):

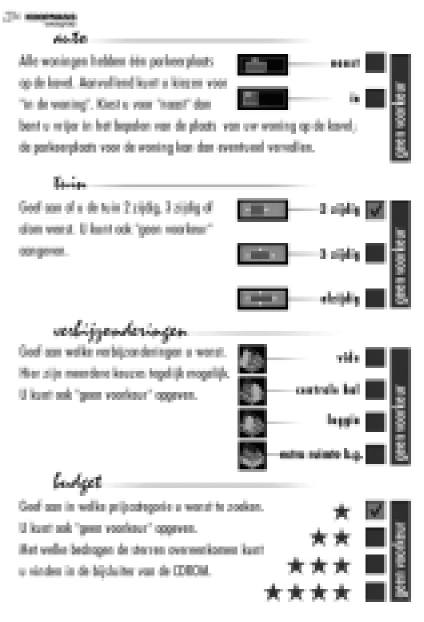


**Figure 6.4: Example of a choice list (in Dutch)**

Most importantly however, it was also realized that the need for more customer influence, and thus better guidance, could change the traditional structure of and roles within the building industry. One architect mentions: ‘The developer will need to re-train his sales manager. This newly born broker will need to outline the process and control it. He or she is the essential player in the network. The initiative-, design- and execution process will proceed via this person. He decides when to appoint the architect or how to translate the customer requirements into the building process. Normally, the developer and architect together play the game of demand (buyer) and supply (product). The buyer of the house now needs to participate in this game and needs to be guided in the development process. The ‘customer is king’, but he is neither a developer, nor an architect, let alone a builder. The customer must be able to surf the Internet, looking for his or her dreamhouse for an affordable price. Wherever this house may be located, whatever the house of its neighbor may look like. There is a new task at hand for a new type of broker who takes on this challenge and who is able to initiate this customer-oriented process. This should lead to a change of roles. The developer becomes advisor, counselor and guardian of the budget. The architect stays in the background; he takes care of the esthetic image, the total picture. The builder takes care of the calculations of the unique custom-made options.’

After the sales period had been concluded the stakeholders were asked about their actual experiences with guiding and supporting the customers during the design process. The survey first held in October/November 2000 and a reminder was sent in February 2001. For most respondents the sales period had almost ended or had already ended during one of these periods. It was learned that some of the non-response was caused by the fact that at the moment of the survey, in some projects most of the houses had not been sold yet. The response rate to this survey was approximately 62%, i.e. we received 28 responses (out of a possible 46): 11 architects, 3 builders, 4 estate agents, 8 builder/developers and 2 housing corporations. The questionnaire itself can be found in appendix 6.

From this questionnaire we defined a variable ABILITY, i.e. the amount difficulty customers had in designing their own house, as a combination of questions 1.1, 1.2 and 1.3. The Cronbach alpha (as the outcome of a scale reliability analysis) of this newly defined variable was 0.783, which is sufficiently high. The following figure 6.5a illustrates the values of this variable graphically.

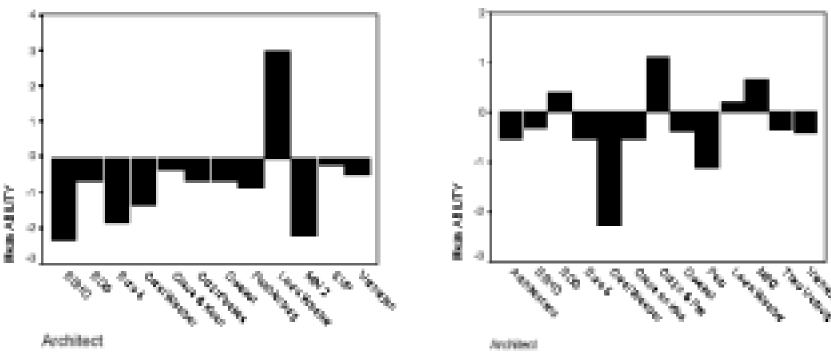



**Figure 6.5a & b: Customer Ability (as indicated by a. organizers and b. customers)**

It can be noticed that especially the buyers of houses designed by architect Laura Weeber had no difficulties in designing their own house. Buyers of the other projects did have more problems and needed better guidance.

We also asked the buyers of the houses by means of a so-called customer investigation about their ability to participate in the design. This investigation was held in two rounds; the first in December 2000, the second in early April 2001. In total we received 105 responses from a total of 270 surveys sent out, a response rate of almost 40%, which is reasonably high. The questionnaire can be found in appendix 7. Four questions/items were used to operationalize customer ability to participate. These were:

- I know a lot about architecture and house design
- I love do-it-yourself work
- I am already experienced with building a house on my own
- Designing my own house was more difficult than I expected

The four items together (the inverse of the fourth item was used) made up the new variable ABILITY, with a Cronbach alpha of 0.6435. The values of this variable for each sub-project have been depicted graphically in figure 6.5b. We can see that there is quite a gap in the majority of the projects between the perception of the organizers (i.e. architects, developers and builders) on the one hand (fig. 6.5a) and the customers themselves on the other (fig. 6.5b). In general, the organizers are often a little more pessimistic about the customer's abilities than the latter are themselves. Obviously, it is important to make a good estimation of the customer's ability in order to know what to offer and how to guide the customer during the design process. A large discrepancy will probably lead to dissatisfied customers or too much organizational trouble.

Second, we wanted to analyze the willingness of the customer to participate in the design. This was simply done by asking the customers whether they wanted to participate in and decide on the design of their own house. The outcomes per sub-project are depicted in figure 6.6.

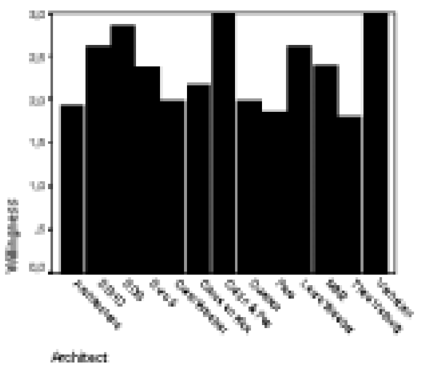



**Figure 6.6: Customer willingness**

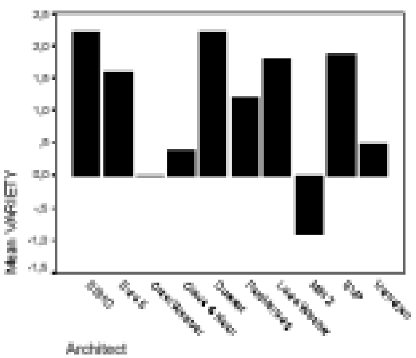



**Figure 6.7: Variety in choices per sub-project**

Not surprisingly, we see that for all projects the willingness to participate in the design is quite high.

Finally, the third variable of the construct 'customer disposition to participate' is heterogeneity of demand. Remarkably and paradoxically enough, it was doubted - beforehand - by a number of stakeholders whether the demands and requirements of the Dutch house buyers were indeed that much heterogeneous and diverse to justify a project such as *Gewild Wonen*. The initiator himself in fact stated: "I think 95% of the Dutch people are happy with the current supply of houses. These people really do not want or need more influence on their house design." Other stakeholders mentioned that in earlier building projects, where customers were also offered more design freedom, it turned out that the great majority of customers all chose the largest variants and did not differ much in other choices either. From the questions:

4. Our buyers had a lot of variation in their choices.
6. Afterwards, it turned out that the majority of the choices offered to the buyers were not selected at all.
7. Despite the fact that all of our houses have been designed by the same architect, they eventually turned out to be very different.
8. Most of our buyers selected the biggest variant, i.e. the house with the largest surface and/or volume.
10. Now that all of our buyers have chosen, it turns out that our houses are quite similar to each other.

(see also appendix 6) we constructed a new variable called VARIETY, which indicates the degree of variety in designs chosen by the customer. The Cronbach alpha of this new variable was 0.7338. Figure 6.7 illustrates the variety per sub-project. We see that for some projects the variety in choices was indeed quite low. This includes the projects designed by MIN2, Carel Weeber and also Claus & Kaan and Verheijen. These projects mostly had the largest variants chosen, while others, such as Laura Weeber's *Growing House,* SVP's *Slimfit Rental Houses*, Bureau 5's *Do you want the main part?* (Hopman) and *Living as only you would like* from BBHD did not experience these outcomes. The explanation for this is not easy to give obviously. Partly it may be caused by the type of house designs, on the other hand, the customers themselves may just have had few financial constraints.

Summarizing, we may conclude that the customer's disposition to participate differs strongly per sub-project. The consequences of these differences may be found in the chosen designs, the use of ICT for customer support and finally customer satisfaction and firm performance. The following sections will shed more light on this.

## *6.5 Product Modularity*

### 6.5.1 Introduction

Most houses in the Netherlands are single-family dwellings. These can be low-rise, mid-rise or high-rise buildings. The architectural principles for these houses are generally the same, therefore the carcasses are comparable too. The carcass is the supporting construction of a house. The shape or size of a house is not accomplished accidentally. First, there is the destination plan of a city. Second, the professional order placer has an important voice in the matter due to the maximum amount of founding costs (SBR 1992).

### 6.5.2 Three product levels

In section 5.3.2 it was argued that a system may have many nested levels. Within each level, many components may be linked to form the next higher level system. This especially holds for houses. Houses are very complex products consisting of numerous elements, which in themselves also consist of numerous elements, etc. For example, one of the smallest distinct elements of a house is often the brick. Other distinct elements may be the roof, the façade, the kitchen, the toilet or the walls. In general, one can distinguish between three generic levels of a house:

- Exterior (*Ruwbouw*), the most rigid level of house design, i.e. the floor plan, volume elements, which determine the shape or exterior of the house.
- Interior (*Afbouw*), the finishing design parts of a house, i.e. roofs, façades, bow windows, use of materials, which determine the infill or interior of the house.
- Accessories, i.e. colors, type of kitchen, which determine the extras of the house.

### 6.5.3 Modular homes

For each of these levels of a house, we may wonder whether the modularity features of the previous chapter are applicable and useful. As an example of high product modularity in the housing industry, we take a brief look at the development of mobile and modular houses, which are especially popular in the United States.

In the early 1960s in the United States the mobile housing industry emerged. This evolution provided the first national, economically successful, mass-produced housing system in North America (Sullivan 1980). The roots of the mobile home industry date back to the 1930s when there were a number of manufacturers producing trailer coaches or travel trailers that later became known as mobile homes. Following the Second World War, there was a tremendous need for low-cost housing and this need provided further stimulus for growth of the mobile home industry. In the years following the industry grew tremendously. Nowadays, more than one million mobile homes are produced per year; ten times the total housing production of the Netherlands. Their success can most likely be dedicated to the fact that they evolved rapidly in response to users' needs and desires. Another consideration that was a major factor in the growth, was the relative cost of mobile homes compared to other forms of housing, caused by the successful application of industrial, manufacturing techniques and the low costs of labor on a volumetric basis and in terms of dollars per man-hour.

One of the outgrowths of the mobile home industry has been the increasing development of what are called 'modular housing systems'. They consist of three-dimensional, volume-enclosing units that are shipped as complete components from a factory and assembled on site. The main difference between 'modulars' and mobile homes is that the latter are assembled on 'mobile chassis' and modulars, in general, are transported to the site on flat bed trucks and set on permanent foundations at the site. Essentially, a modular unit is thought of as a 'box', with all the internal or external features and finished completed in the factory, and only the connection to adjoining units and the hook-up of services are completed at the site.

Within the modular houses we can distinguish wet cores or service modules. They are special modular components for housing that contain all the electrical control and mechanical and plumbing services required for a single housing unit. The module often contains the completed bathroom and kitchen, including all interior fittings and finishing. These units simplify planning and scheduling of construction and overall construction time can be reduced, as the amount of time to install services is greatly decreased. Furthermore, it fixes a major portion of the construction costs early in the design and planning stage which in turn permits more accurate cost estimating.

When we take these modular homes as the extreme case of product modularity in the housing industry, a number of issues are apparent. First, we see that the distinctiveness of components is present at the level of the exterior: the components are the 'boxes', which are constructed at the factory, including their internal and external features. Second, the coupling between the modules is loose; they have been developed independent of each other. Third, the mapping between functions and components is also quite clear: entire bathroom, kitchen or plumbing components are designed, where the function of the 'boxes' is to add volume to the house. Fourth, whether the interfaces between the modules are indeed standardized remains unclear. It is stated that 'only the connection to adjoining units and the hook-up of services are completed at the site'. Most likely however, connecting the adjacent modules will be a standard procedure, thus we may assume that the interfaces are indeed standardized to some extent.

As a consequence, these modular homes are easy to disassemble and re-assemble at another location, while most of these houses are mobile houses. This enables easy interchangeability of components. Furthermore, because of the modular structure, a major portion of the construction costs are fixed early in the design and planning stage which in turn permits more accurate cost estimating. This reduces the development risks of the customer. Rather surprisingly perhaps, no relation is made between customer involvement in the design and the need for the houses to be modular. Still, our preliminary operationalization of product modularity seems to be applicable and valid and we will therefore continue to use it during the application of the case.

### 6.5.4 Modular Coordination in Product Design

In 1961 Habraken initiated this system in his book '*De dragers en de mensen*' (The supporters and the people). Between 1965 and 1975 he tried to carry out this system, together with the Foundation for Architect Research (SAR). The idea was that the government and building companies should build large three-dimensional supporters, where the occupants subsequently could design their house using industrially manufactured infill packages. According to Habraken a balance needed to be found between where the building production stops and where man enters the process with his own gear and equipment. Habraken wanted to move this border towards more industrial production and more standardization. The individual usage of industrially manufactured products had to be expanded to the level of contours, materialization and layout of the house. The SAR stressed the clear separation between things that were fixed and things that were not.

As mentioned above, such a system requires that the previously mentioned elements – or modules - must be produced and assembled, such that they can be easily replaced. The norm NEN 6000 'Modular Coordination for Buildings' prescribes numerous ways in line with this philosophy. This norm has been introduced to stimulate industrialization and standardization in the building industry. It allows decoupling of decisions and products in the building industry. We refer to Carp (1982) for more information on modular coordination, which in itself is a very technical description of different types of design plans used during the design phase that lies outside the scope of our research. For now, it is sufficient to know that technically, the housing industry has been working on industrial engineering and modularization to stimulate flexible house designs for a number of years already. We wonder to what extent these techniques have been used in the *GW-project*.

### 6.5.5 Product modularity in *Gewild Wonen*

In this section we will describe how we grouped the project into four types, based on the way modularity is used. For each type we will single out one particular sub-project that nicely illustrates exactly how modularity has or has not been used on product level. The four types are denoted as:

1. Variant
2. Core
3. Sectional
4. Free

**Variant Type**

The first type is the Variant type. An example of this type is the project, designed by Claus & Kaan and developed by NCB, entitled *Choosing creatively, living recreatively*. In this project, buyers can choose out of five basic variants. The five basic variants all have fixed floor plans, based on a certain predetermined style: adventurous, serenity, family, atelier or hospitable. The reasoning behind this design is explained by the developer who states: "Maximal freedom of choice leads to indecisiveness. Therefore, we chose to offer only five basic types. Within each type two variants per floor are offered. The final step is the choice of a number of options. In our opinion customers are not able to deal with much more variants; they are better serve with a limitation of the number of choices to make and clearly defined guidelines."

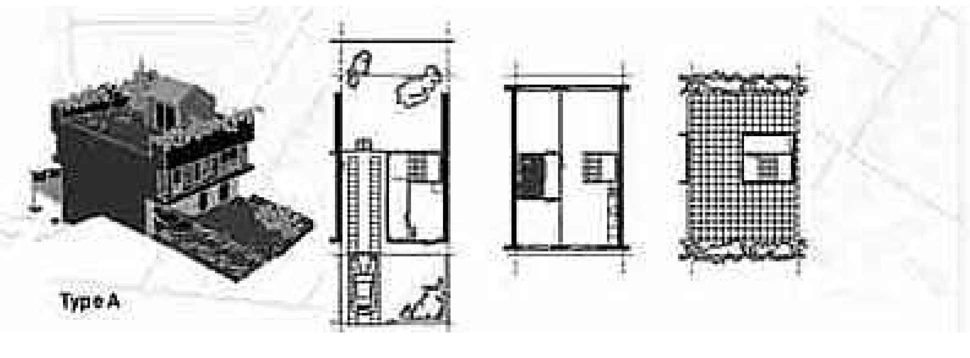



**Figure 6.8: Two variants of NCB's Choosing creatively, living recreatively**

The modularity features, defined in section 5.3.5, for this project are as follows:

| |
|---|
| **Distinctiveness of components**<br>Hardly any distinction can be made between the components; the house is offered – and developed – as an integral part. The modules only become distinct on the level of the accessories; no exterior and interior modules are defined. |
| **Loose coupling between modules; tight coupling within modules**<br>No, the modules are very tightly coupled with each other and cannot be seen independently. |
| **Clarity of mapping between functions and components**<br>Functions of a house are all combined in the one integral component: the variant offered to the customer. |
| **Standardization of interfaces**<br>Because it is not possible to distinguish different modules, the issue of standardized interfaces between them is irrelevant. |

**Table 6.6: Modularity features of *Choosing creatively, living recreatively* project**

The only other project that shows great similarity with the previous project is:

- *Living as only you would like* by BBHD and WVA

What these two projects have in common is that they only offer house variants to the customers, i.e. buyers may choose from a (limited) set of basic, standard houses, which they can further enhance with numerous accessories. The exterior as well as most part of the interior are fixed however. Therefore, we may conclude that the degree of modularity of these projects is relatively low. We will see more modular house designs in the remainder of this section.

**Core Type**

The second type is the Core type, illustrated by the *Living in a blockhouse* project, developed by Duvekot Architects and Rehorst Bouw. In this specific project, the buyers can become order placer by choosing a number of blocks and grouping these blocks according to their own requirements. On a plot six foundation blocks of 4x4 meters are installed, in a 2 by 3 grid. Each house is limited to two floors, so each house can maximally consist of twelve blocks. Buyers can make a selection out of these twelve blocks and thus configure their own 'block-house'. One of the blocks contains the entrance, the toilet, the stairs, the storage room and the installations. On the second floor a standard block is installed with bathroom, stairs and installations as well. Both blocks are compulsory in each house. The latter feature of this design, the core module, is the most important feature of the projects of the so-called Core type.

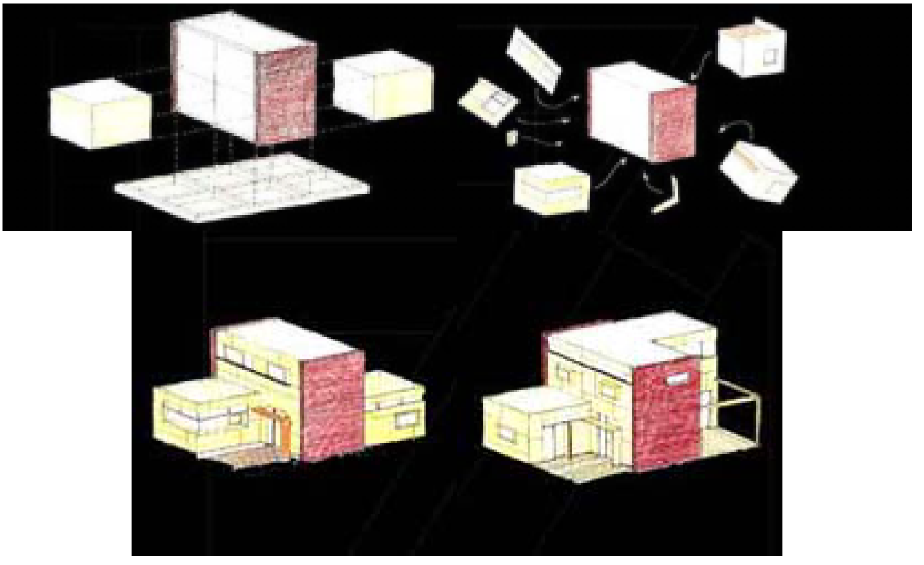


**Figure 6.9: The Core type designed by Duvekot**

This project is one of the projects that actually apply modularity on the level of the exterior. The modules are the twelve blocks, which may be selected - or not - by the buyer. with only two of these components with a pre-determined function. Let us discuss the different features of modularity for this house design.

| |
|---|
| **Distinctiveness of components**<br>The exterior components the house is built from are clearly distinct from each other. They can be individually selected by the customer. The additional modules – to be added to the core, if preferred – are also clearly distinctive. |
| **Loose coupling between modules; tight coupling within modules**<br>Although it may seem that the exterior modules are loosely coupled and are fairly independent of each other, the presence of the core module – with, for instance, a fixed position on the plot - increases the tightness of the coupling between the modules. This means that a change in the core module affects the use of the other – additional – modules. |
| **Clarity of mapping between functions and components**<br>Because of the core module (or two) that contains many functionalities the clarity of the mapping is not very high, although higher than with the Variant type. The function of the additional modules is on the other hand quite clear: volume. The main reason for adding these modules is to increase the size of the house. |
| **Standardization of interfaces**<br>Ideally, the core module could be equipped with standard interfaces to create some sort of bus on which the additional modules could easily be attached. However, in practice this is difficult to realize; most of the connections are unique, each requiring unique design solutions. The designs that focused on extendibility of the house in a later stage, tried to use (or develop) as much standard connection interfaces as possible in order to allow for easy addition and replacement of modules in a later stage. |

**Table 6.7: Modularity features of *Living in a blockhouse* project**

Summarizing, we may argue that this particular project exhibits a medium degree of modularity on the exterior level and a high degree of modularity on the interior level. The core module automatically limits the degree of modularity of the design. Other projects – the majority within *Gewild Wonen* - that exhibit the same degree of product modularity are:

- *The islands: Flexible watervillas*, by UN Studio and Visser
- *The Growing House*, by Laura Weeber and ABB
- *The reflection*, by BDG and Verwelius
- *Personal house & garden style*, by FARO and Bemog
- *Do you want the main part?* By Bureau 5 and Hopman
- *Personal housing* by Carel Weeber and ERA
- *The Kettlehouse* by M.Rohmer and GSA
- *Slimfit rental houses* by SVP and Goede Stede
- *Pierhouses* by Verheijen|Verkoren|De Haan and Proper Stok

Once again, the common features of these projects are: the use of a core module, equipped with (most of) the necessary facilities such as the entrance, the stairs, the sanitary provisions and the storage rooms. In addition to this core module buyers can select extra modules, mostly for extra volume.

**Sectional Type**

The third design type is Sectional[17] design, exemplified by the project designed by Colijn & Feekes and developed by GBV Zondag, called *Pioneers in the Polder*. The house is assembled from several design modules, sized 3.30mx3,30m. A few function specific modules have been developed, for sanitary, entrance and the stairs, but contrary to the previously described designs (the Core type), these function modules are not part of a core module. Buyers are free to locate these modules wherever they want, within the rules defined by the architect. These rules were formulated to ensure privacy, sunshine and unity in total image; for the rest the buyer is completely free to design his house. This includes shape of the house, layout of the rooms, type of roof, colors, materials and the front door.

**Figure 6.10: Sectional design by Colijn & Feekes**

[17] Named after one of the modularity types defined by Pine (1993): sectional modularity. Sectional modularity allows the configuration of any number of different types of components in arbitrary ways – as long as each component is connected to another at standard interfaces, e.g. Lego. Key is to develop an interface that allows sections or objects of different types to interlock.

The modularity characteristics for this project are:

| |
|---|
| **Distinctiveness of components**<br>Just as the Core designs, the modules are clearly distinct from each other. |
| **Loose coupling between modules; tight coupling within modules**<br>Compared to the Core design, the coupling between the modules is loosened. |
| **Clarity of mapping between functions and components**<br>Because there is no core module, the mapping of functions and modules has become clearer; dedicated sanitary modules, entrance modules and even stairs modules have been developed. |
| **Standardization of interfaces**<br>The interfaces are the crucial part of the design. They have been designed as simple as possible with as little different interfaces as possible. This means high standardization of interfaces, although the architect admitted that this is often not the most economic solution, i.e. involving high development costs. |

**Table 6.8: Modularity features of *Pioneers in the Polder* project**

In summary, we may say that the degree of modularity of this project is relatively high, i.e. higher than the previous two design types, Variant and Core. The other project with the same modularity features is:

- *Multiple Choice* by ArchitectenCie and Koopmans

**Free Type**

The fourth and final project to be discussed in detail is the project by Proper Stok and Verheijen|Verkoren|De Haan, called *All hands on deck*. This project is in itself once again divided in three different sub-projects. The first has been designed according to a fixed measurement system. The core module already exists, but the interior is fully free to choose, e.g., innerwalls, doors, bathrooms, kitchens, extensions, balconies and piers. It is a clear example of a so-called Core design. The second only consist of a carcass: two building walls, a roof and a metercupboard. The actual house is fully designed and built by the buyer. The building walls are however equipped with several holes, to place a floor at every level desired. The roof has this construction as well. This design may be grouped under the Sectional designs. The third, with the most freedom for personal expression, is a floating concrete boatcarcass. This is the foundation for the future house. It contains a standard starting tower, where people can live in during the building process. For the rest, people can fully build their own ‘dreamboat’. This design cannot be grouped under one of the three previously defined types, it a type of its own, which we will call the Free type.

**Figure 6.11: The Free dreamboat design of Verheijen**

The following table illustrates the inappropriateness of the modularity features for this design.

| |
|---|
| **Distinctiveness of components**<br>Besides the starting tower and the floating carcass no distinct modules can be identified nor are they developed by the architect. It is the customer himself who decides what the house will look like.<br>This also means that the other three features below are irrelevant and non-applicable. |
| **Loose coupling between modules; tight coupling within modules**<br>Non-applicable |
| **Clarity of mapping between functions and components**<br>Non-applicable |
| **Standardization of interfaces**<br>Non-applicable |

**Table 6.9: Modularity features of *All hands on deck* project**

We thus see that determination of the degree of modularity in this case is irrelevant and unuseful. The design made by the architect only provides the basic needs; the remainder of the house is designed and built by the customer himself. The architect mentions the following in this respect: "Carcasses should be manufactured by serial production, to profit from the economies of scale. Building companies are specialized in these rigid way of working, using large equipment. However, they often fail in the interior. Therefore, this should be the responsibility for the buyer of the house, the occupant. When the carcass is ready, this buyer should be able to take the rest of the work literally on his shoulders." So, this architect does not mention choice options, questionnaires or variants; he offers the customer almost complete freedom.

The other project closely similar to this project, at least with respect to the use – or rather: non-use - of modularity within the project is:

- *Free-style living*, by MIN2 and Credo

Table 6.10 below summarizes the four design types and their features, from which we learn that there is an upper limit to the usability of modularity with respect to customer freedom.

| Type | Product Modularity | Customer freedom |
|---|---|---|
| **Variant** | Low | Low |
| **Core** | Medium | Medium |
| **Sectional** | High | High |
| **Free** | Non-applicable | Highest |

**Table 6.10: Four design types and their features**

## *6.6 Process Modularity*

### 6.6.1 The primary process of a building project

The next effort concerns the applicability and usefulness of the concept of process modularity in the housing industry. First, to investigate whether our early operationalization is valid, we will discuss the primary process of a building project.

The primary process of a building project often consists of five different phases (Voordijk 1994):

1. Initiative phase, where a Program of Requirements (PoR) is formulated. The PoR is the link between the requirements of the customer and the design. It contains usability requirements, functions and conditions. The order placer of a project, who formulates the Program of Requirements, could be the actual user of a building, an administrator or a property developer. In general one can distinguish between professional and incidental order placers (SBR 1996).
2. Design phase: translation of Program of Requirements into a final design. The design phase results in a package of information destined for the executing building company. Based on the final design it is determined which activities need to be performed during the execution phase. Which resources and building materials are used and what quality should they have? This information is contained in the Building Specifications. Within this phase several organizational models are possible. In general one can distinguish between six different models (SBR 1996), which will be discussed in section 6.7 when supply chain modularity is discussed.
3. Execution phase: specifications and drawings are analyzed and the building method is determined. Plannings are made, based on the chosen organization model, other parties are approached to participate in the project. Decisions are made whether or not to outsource certain activities.
4. Delivery: When all execution activities have been performed the building is ready to be delivered.
5. Usage: Finally, the building can be used for what it was destined to.

Figure 6.12 illustrates the five phases of the primary building process:

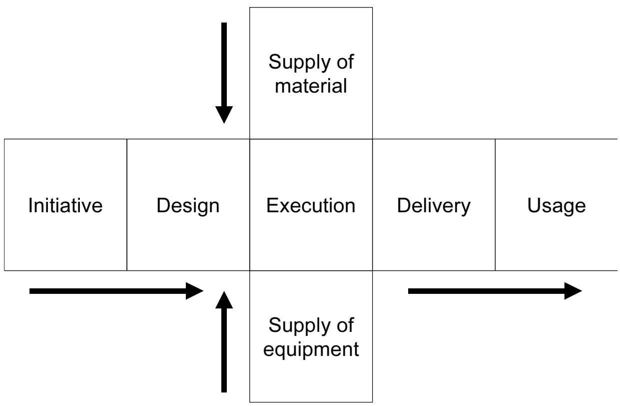



**Figure 6.12: Five phases of the primary building process**

### 6.6.2 Building methods

It was mentioned earlier, in section 5.3.4, that we want to distinguish between intra- and interorganizational processes and structures. The former refers to process modularity, while the latter is related to supply chain modularity. In our case, process modularity deals with the modularity of production techniques and procedures – i.e. the way *how* a product is made, while supply chain modularity refers to *who* does it and *how* the different parties involved interact with each other. Both dimensions are obviously interconnected, but separated as well. In the case of a housing project this implies the following.

Process modularity in the house building industry does not refer to the modularity of the five previously mentioned phases of a building project. It refers to the building methods used during the execution phase. The building methods are the most important production and manufacturing methods used in the building of a house, they greatly determine the final appearance of a house (SBR 1992). In line with our definition of process modularity (section 5.3.3) and the accompanying features the building method is the most obvious operationalization in this case study.

On the other hand, supply chain modularity more closely resembles the five phases of a building project. We already saw that during these phases decisions are made about whether or not to outsource certain activities, which parties to contract and so on. These are especially the features of interest for determining the degree of supply chain modularity. The name given to these decisions in the building industry is the organizational model. The type of organizational model chosen determines the relationships between the different parties involved in a project, their agreements and contracts and the division of risks and responsibilities. In the next section (6.7) we will analyze whether we can apply the features of modular supply chains on this model. The remainder of this section will be dedicated however, to process modularity.

We will discuss a number of different production methods and techniques, used in the building industry, i.e. brick, concrete, assembly and woodframe construction. The choice of a certain method has its implications for the technical and organizational realization of the houses and the logistic points of attention with respect to the preparation of the actual production. After the methods are introduced we will link them with our framework and discuss whether the features of process modularity are applicable to these methods and subsequently we will try to make a categorization of low and highly modular methods.

**1. Brick building**

A brick building carcass consists of brick blocks or elements (mostly made of plaster sandstone bricks), which are built or glued together. For decades, houses have been built with this method in the Netherlands. A brick house is lighter than a house made of concrete, but heavier than a woodframe house. A brick building carcass consists of many separate elements that have to be assembled on the building place. On the basis of a delivery scheme the different parts arrive at the building site.

**2. Concrete building**

Concrete is an often-used material in the building industry, also for houses. A mold carcass emerges by pouring fluid concrete in a formwork. In mold building many tunnel formworks are used, where floors and wands are poured out at once. Mold building requires a serial approach.

**3. Assembly building**
With this building method large prefabricated elements are assembled into a house. It mainly concerns two different materials: elements of prefab concrete and elements of gas-concrete. The latter is fairly light and possesses good heat-isolation, the former is heavier and isolates sound reasonably well. For quite a long time this building method was considered only adequate for large series of equal houses. Nowadays, the method has been refined and is capable of dealing with small series of equal elements. Therefore, in theory, the number of different varieties is not less than those of the other methods. The delivery and assembly of the carcasses is often executed by subcontractors; specialized assembly teams take care of the assembly. The assembly of the prefab elements is done in a sequence, calculated in advance, in which the elements arrive at the building site.

**4. Woodframe building**
Since the middle of the 70's increasingly more woodframe houses have been built in the Netherlands. The method has a foreign origin and has been adapted to Dutch norms and requirements. Woodframe carcasses are fairly light and in most cases one uses prefab elements, for wands, floors and roof. The external finishing determines whether a woodframe house actually looks like a wooden house.

Table 6.11 below compares the four building methods on a number of factors:

| | Brick | Concrete | Assembly | Woodframe |
|---|---|---|---|---|
| **Labor hours in factory** | Few | None | Many | Many |
| **Labor hours at building site** | Many | Less than brick | Few | Few |
| **Preparation time** | Short | Longer than brick | Long | Long |
| **Execution time** | Long | Shorter than brick | Short | Short |
| **Logistics** | Versatile, simple | Deploy of tunnel very complex | Transport and assembly | Transport and assembly |
| **Facilities house installation** | Afterwards, on location | Pouring during production | In factory | On location |

**Table 6.11: Comparison of four building methods (source: SBR 1992)**

## 6.6.3 Process modularity

Based on the previous information on the building methods we may now be able to analyze the process modularity of these methods, using the features of process modularity discussed in section 5.3.3. With respect to the degree of process modularity of each of the four methods, the following table is formulated.

| | Brick | Concrete | Assembly | Woodframe |
|---|---|---|---|---|
| **Distinct/autonomous components** | 2: Glueteam & floorteam | 1: Tunnelteam | 3: Foundation, assembly and interior finishing | Variable, depends on the contractor (appr. 1 to 5). |
| **Coupling and interdependency** | Tight | n.a. | Medium | Loose |
| **Mapping** | Medium (17:2) | Complex (31:1) | Clear (8:3) | Medium (22:(1-5)) |
| **Standardization of interfaces** | High | n.a. | High | High |

**Table 6.12: Modularity features and four building methods**

The reasoning behind table 6.12 is the following. A process component or module was defined as: a distinct part of the production process of an organization that embodies a core design concept and performs a well-defined function (see section 5.3.4). Just as with product modularity we can distinguish many different (nested) levels within a production process. To avoid too much complexity and detail we limit ourselves to the level of the production team; a team of several persons taking care of specific tasks. Within each production technique one can distinguish a number of distinct components. For each technique these components are given in table 6.12. The coupling of these components depends on their mutual dependencies. In the case of brick building the glueteam and the floorteam cannot operate independently of each other; they need to operate in close, tight cooperation. The woodframe teams can operate more unrestrictedly, separately from the other teams. Mapping of functions and components describes the total number of tasks divided by the number of teams. For instance, in the case of brick building, the two teams together take care of 17 clearly defined distinct tasks (SBR 1992:69-70). This denotes a fairly complex mapping between functions and components. Finally, standardization of interfaces refers to the degree in which the transition of one component to another takes place, i.e. how easily and standardized can one component (a production team) hand over or transfer the work to another team; how specific or generic is the outcome of one team for the other team to use it? Is it the same for each house or different every time, dependent on numerous external factors and conditions. It was found that for each method the interfaces are standardized and well defined to a large extent.

Summarizing, we come to the following typology in degree of process modularity of the four methods:

| Method | Process Modularity | Preparation and execution | Proximity in time and place |
|---|---|---|---|
| **Brick** | Medium | Short preparation, long execution time | Medium |
| **Concrete** | Low | Medium preparation, medium execution | High |
| **Assembly** | High | Long preparation, short execution | Low |
| **Woodframe** | Highest | Long preparation, short execution | Low |

**Table 6.13: Process modularity of the four building techniques**

From the same table, we also see that the operationalization used by Fine (1998), i.e. proximity in time and place, by using the information about preparation and execution times, results in the same process modularity classification. This shows that this operationalization may be useful – and sufficient - as well. By no means do we claim to have fully analyzed all building methods, neither do we claim that these four building methods cover the entire process modularity spectrum of the housing industry. It is merely a rough and relative indication to be able to compare the four methods within the case study and translate them to our framework.

### 6.6.4 Process modularity in *Gewild Wonen*

As a next step we will classify the *GW-subprojects* according to the previous operationalizations of process modularity in the building industry. We will group the projects according to the four types of designs defined in the section on product modularity (section 6.5). In this manner we obtain a good impression of the relationship between product and process modularity immediately.

| Design type | Project name | Architects | Product modularity | Process modularity |
|---|---|---|---|---|
| **Variant** | Choosing creatively… | Claus & Kaan | Low | Low (concrete) |
| | Living as only you would like | BBHD | | Low (concrete) |
| **Core** | Living in a block-house | Duvekot | Medium | Medium (brick) |
| | The islands: Flexible watervillas | UN Studio | | Low (concrete) |
| | The Growing House | Laura Weeber | | Medium (brick) |
| | The reflection | BDG | | Medium (brick) |
| | Personal house & garden style | Faro | | High (woodframe) |
| | Do you want the main part? | Bureau 5 | | Medium (brick) |
| | Personal housing | Carel Weeber | | Depends on facade |
| | The Kettlehouse | M Rohmer | | Medium (brick) |
| | Slimfit rental houses | SVP | | High (woodframe) |
| **Sectional** | Pioneers in the Polder | Feekes Colijn | High | Medium (brick) |
| | Multiple Choice | ArchitectenCie | | High (stealframe[18]) |
| **Free** | All hands on deck | Verheijen | Non-applicable | Low (concrete) |
| | Free-style living | Min2 | | Medium/High (brick&woodframe) |

**Table 6.14: Process modularity of different housing projects**

Summarizing, we notice quite a strong relationship between product and process modularity. Designs that only offer a limited number of variants to the buyers can make use of a building technique that exhibits low process modularity, while on the other hand, more modular house designs, mostly rely upon more modular process techniques, such as brick or woodframe building. Obviously, in the case of the fourth product design type, Free, the majority of the building process is carried out by the buyer himself or under his direct supervision. It is expected that these buyers will choose building techniques with a high process modularity, such as woodframe building, for finishing the house.

In the final questionnaire we asked the participants about the influence and suitability of the building method they used for *Gewild Wonen*. They were asked, among other things, whether the increased customer influence forced them to use a different building technique than they were specialized in, whether they had to develop new building techniques and whether the building method is the most important factor that determines the eventual freedom of choice for the customer.

The following graphs depict the answers given to the questions:

In the *Gewild Wonen* project we were forced to deviate from our favorite building method.
The building method we used is in fact not very suitable for a project such as *Gewild Wonen*.
More investments must be made in the development of flexible building techniques that enable more freedom of choice for the buyer.
The chosen building method is the most important factor that eventually determines the freedom of choice for the customer.

[18] Instead of using a well-known method, like brick or concrete building, the developers chose a different method: a *metalstut* system, also called stealframe building. Stealframe building is comparable to woodframe building, only the materials used are different.

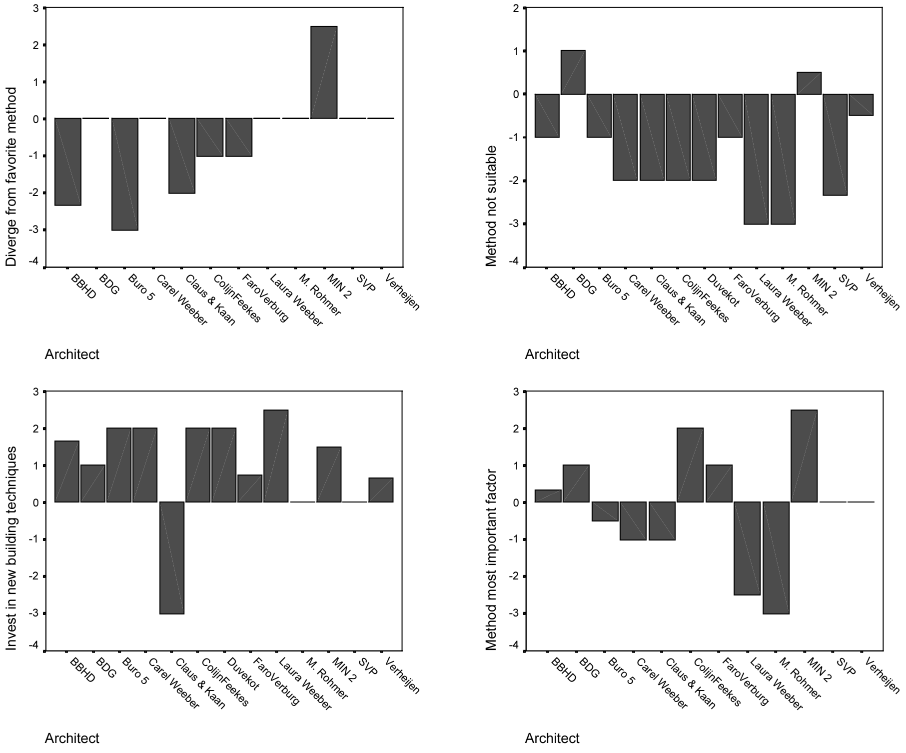



**Figure 6.13: Graphical representation of answers to the four questions**

It can be noticed that especially architect MIN2 and developer Credo were not very happy with their chosen building method (a combination of brick and woodframe building). BDG, with developer Verwelius, were not very satisfied with the suitability of their method either. The majority of the respondents agrees with the statement that investments are needed in the development of new, innovative building techniques that enable more customer freedom. Only Claus & Kaan / NCB strongly disagrees with this proposition; they feel that the current building techniques are suitable enough. The fact that they chose concrete building further exemplifies this.

Furthermore, strong controversy exists with respect to the question whether the building method is the most important factor that determines the eventual freedom of choice for the customer. The participants in the project designed by MIN2, once again, most agree with this statement.

Finally, we observe that the newly defined variable VARIETY (see section 6.4.3) shows significant correlations with the previous four questions. This sound logical as an unsuitable building method leads to lower customer freedom and little variation in design.

## *6.7 Supply Chain Modularity*

### 6.7.1 Organizational models

As mentioned above, the initiative, design and execution phase are strongly related to each other; they could even overlap or be integrated. The way the parties cooperate during the project strongly determines the way a building project progresses as well. The moment when parties start to get involved in the project can differ. Furthermore, the type of contracts agreed upon, the way prices are effectuated and the way risks are divided over the participants may be different too. The exact way the different stakeholders cooperate, how risks and responsibilities are divided and which roles are fulfilled by the stakeholders, is determined by the chosen organizational model. Six organizational models are distinguished (SBR 1996), divided in two categories. In the first category the design and execution responsibilities are separated, where in the second category these responsibilities are combined. The traditional approach, the building team and management contracting belong to the first category, general contracting, design-and-build and brochureplan to the second. Below all six models are discussed, followed by a short discussion on the advantages of certain models in specific circumstances. At the end of this section the link is established between the models and supply chain modularity.

**1. Traditional approach**
In this model, the order placer deals with two (type of) parties: the designing party or parties, responsible for the design, and the contractors, responsible for the execution. Both are directed and contracted by the order placer. The order placer could offer the complete assignment to one architect, who can subcontract other advisors on his own, or offer separate assignments to different designing and advising parties. The same holds for the executing parties.

**2. Building team**
The order placer, the architect, several specialists (advisors) and one or more executing building companies constitute a building team in the design phase. This building team is bounded to a specific project and therefore, unique. The team collectively realizes the design. It is not obvious that the building companies in the team always can claim the right of execution. The contractual agreements between order placer and order taker are comparable to the traditional approach.

**3. Management contracting**
This type of cooperation originates in Great Britain. In an early stage of the process an execution expert is involved in the project. This management contractor has been selected on the basis of his management qualities and execution expertise. His task is to advise the order placer about execution and cost aspects in the design phase, to contract the building partners and to coordinate their activities. The management contractor does not participate in the execution phase; he receives management allowance.

**4. General contracting**
One organization (a general contractor) takes care of the entire coordination of the design and execution processes and bares full responsibility for the project. Contract-wise the general contractor stands between the order placer and the other participants, which he selects and contracts himself.

**5. Design-and-build / turnkey**
In this model one organization (a single company, a joint venture or a group of companies) is responsible for both design and execution. The order placer deals with one contact point and enters into one agreement for the entire project. The order placer thus gives away the responsibility of the project.

**6. Brochure plan**
In this case, the offering party uses 'brochure plans', which are standard building plans that are project and location-independent. The party offers off-the-shelf products to the market, which can be adapted, within certain borders, to the requirements of the buyer.

**Table 6.15: Six organizational models (SBR 1996)**

The traditional organizational model is more and more threatened by other organizational models. The oldest is the building team, but several other models emerged as well. Managing the building process has been subject to separate contracting; outsourcing of the design to the builder – design & build / turnkey – has been well established. Often the exploitation of a building has become so prominent that the building contract has become part of the entire exploitation contract. All these different types of contracting and cooperation differ from the traditional model because the role of the order placer has been changed dramatically. In most cases, the order placer is still the initiator of the building project, but his involvement and liability have been changed (except for the building team). In the building team the order placer still fulfills his common role; the novelty in this model is the role of the contractor, which is already enlisted during the design process. For the other organizational models, the order placer's is less dominant. With management contracting coordination and control is left in the hands of an expert. In more integrated models, such as design-and-build, the order placer has given away his role concerning the design and process control almost completely.

In general, the order placer decides which organizational model to use. Which organizational model an order placer should choose depends on many factors. The SBR study of 1996 mentions several contingent factors and criteria. Table 6.16 below illustrates these factors and the suitability of each model with respect to each factor.

| | **Organizational model** | | | | | |
|---|---|---|---|---|---|---|
| | **Separation of design and execution** | | | **Combination of design and execution** | | |
| **Criteria** | **Traditional** | **Building team** | **Management contracting** | **General contracting** | **Design & Build** | **Brochure - plan** |
| **Investment Costs** | | | | | | |
| - Early security | 5 | 4 | 4 | 2 | 2 | 1 |
| - Optimal cost/quality ratio | 2 | 2 | 2 | 3 | 4 | 3 |
| - Reduce risk of fulfillment | 3 | 3 | 3 | 2 | 1 | 1 |
| - Maximal market conformity | 1-5 | 1-5 | 1-5 | 1-5 | 1 | 2 |
| **Quality** | | | | | | |
| - Phased assessment / permanent control | 1 | 1 | 4 | 4 | 5 | 5 |
| - Market conform real estate | 1-5 | 1-5 | 1-5 | 1-5 | 1 | 2 |
| - Reduce risk of execution | 5 | 2 | 3 | 3 | 1 | 1 |
| - Reduce risk of exploitation | 5 | 4 | 2 | 2 | 1 | 4 |
| - Conformation with existing plan offering | | | | | 1-5 | 1 |
| - Reduce risk of development | 5 | 3 | 3 | 3 | 1 | 1 |
| - Reduce risk of performance | 3 | 2 | 1 | 1 | 1 | 3 |
| **Time** | | | | | | |
| - Shortest throughput time | 5 | 2 | 5 | 2 | 2 | 1 |
| - Deciding in phases | 1 | 2 | 2 | 2 | 4 | 5 |
| **Organization** | | | | | | |
| - Limitation of number of contractual partners | 5 | 4 | 4 | 2 | 1 | 1 |
| - Little knowledge required for order placer | 4 | 4 | 3 | 2 | 2 | 2 |
| - Clarity about responsibilities of participants | 1 | 3 | 3 | 2 | 1 | 1 |

**Legend:** 1 = Best fit … 5 = Worst fit

**Table 6.16: Criteria for choosing a certain organizational model (SBR 1996)**

According to SBR (1996) the influence of the customer is highest in the traditional approach and decreases towards the brochure plan, where his influence is lowest. In general, the degree of control and influence an order placer has in the project together with the risk of fulfilling the project determine which model an order placer should choose. Figure 6.14 illustrates this:

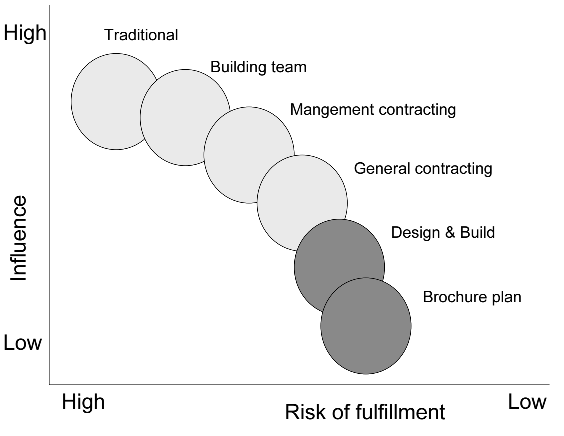



**Figure 6.14: Choice of organizational model (SBR 1996)**

After these analyses we notice the deep level of possible influence of the customer in the building industry on the design of the supply chain, especially in the more traditional organizational models. The customer can determine the design of the supply chain himself, if he wants to and is able to. The choice of a model can depend on what type of order placer is involved in the project. Table 6.17 depicts the relationship between the type of order placer and the 'best' choice of an organizational model (SBR 1996):

| | Organizational model | | | | | |
|---|---|---|---|---|---|---|
| | Separation of design and execution | | | Combination of design and execution | | |
| **Type of order placer** | **Traditional** | **Building team** | **Management contracting** | **General contracting** | **Design & Build** | **Brochure - plan** |
| **Incidental order placers** | ++ | + | * | * | ++ | * |
| **Professional order placers:** | | | | | | |
| ***Own accommodation*** | ++ | + | * | * | ++ | * |
| ***Investors*** | - | ++ | * | * | ++ | * |
| ***Social house builders*** | + | ++ | o | o | ++ | * |
| ***Property developers*** | - | ++ | o | o | ++ | * |

**Legend:** ++ = most relevant, + = relevant, o = neutral, - = less relevant, * = depends on circumstances

**Table 6.17: Relationship between order placer and the 'best' choice of an organizational model (SBR 1996)**

Most of the times, customers in the housing industry are professional order placers, who are frequently involved in building projects and are experienced with the roles played by the building partners in the organizational model. Professional order placers could be their own lodgers (such as banks, governmental organizations or libraries), investors, social house builders or property developers. The other type of order placer is the incidental order placer, who only places an order once in every five years at most. These order placers in general have little knowledge about the fulfillment of a building project. They need to insource the required knowledge from somewhere to make their project successful. This immediately stresses the tension between the customer's disposition to participate and the design of the product, processes and supply chain, as proposed in section 5.4.1. Especially in the case of Gewild Wonen, where all order placers are in fact incidental order placers, this tension will be of main concern. We will come back to this in section 6.12 when the propositions are discussed.

### 6.7.2 Modular supply chains

After having determined which models are best used under certain circumstances, we want to analyze the supply chain modularity of each of these models. We will use the same four features as used for determining product and process modularity, complemented with two additional features: type of coordination and autonomy of modules. The latter two are supply chain specific features, which are also related to the degree of modularity of a supply chain, as we have seen in chapter 5. Table 6.18 depicts the supply chain modularity features of the six organizational models:

| | **Organizational model** | | | | | |
|---|---|---|---|---|---|---|
| | **Separation of design and execution** | | | **Combination of design and execution** | | |
| **Type of order placer** | **Traditional** | **Building team** | **Man'ment contracting** | **General contracting** | **Design & Build** | **Brochure - plan** |
| **Distinctiveness/autonomy of components** | Highest | High | High | Medium | Low | Low |
| **Coupling and interdependency between modules** | Loosest | Loose | Loose | Medium | Medium | Tight |
| **Clarity of mapping between functions and components** | High | Low | Medium | Medium | High | High |
| **Standardization of interfaces** | Low | Low | Medium | Medium | High | High |
| **Coordination by…** | Order placer | Team | Expert | General contractor | Joint venture | Plan |

**Table 6.18: Modularity features of the six organizational models**

The reasoning behind table 6.18 is the following. Distinctiveness of components refers to whether certain supply chain functions or tasks are carried out by a single organization or not and whether they can be explicitly distinguished from others. Which organization, or business unit takes care of certain tasks? In other words it (partly) refers to the degree of vertical integration and degree of autonomy of the participants within the chain. First, it can be noticed that the organizational models, which combine design and execution are less modular than the other three. The distinction between the two tasks – design and execution - disappears in full or partly in the former case. Some of the organizations involved, such as the order placer, voluntarily give up their autonomy, in favor of another supply chain component. Subsequently, of the models with separation of design and execution, the distinction between the components is most clear in the traditional model, followed by the building team and management contracting. The other organizational models combine design and execution; the distinctiveness of components is thus less clear. Consequently, the coupling between the modules of the former models is more loose than for the other models, where design and execution are combined. The third feature is the clarity of the mapping between functions and components, i.e. the number of functions carried out by the different components and their mutual relation. In the traditional outsourcing model it is perfectly clear and well defined, which party takes care of what part of building process. As a matter of fact, only after the order placer knows what will be built does he invite other parties to participate in the fulfillment process. These parties submit quotations; the order placer bases his selection on these quotations. In the building team the clarity is the lowest, because the entire team, consisting of the architect, the order placer, the builder/contractor and a number of other experts, together makes all the decisions and divides the tasks and responsibilities.

The interfaces, i.e. the trade procedures and contracts, are less standardized in the traditional model and building team as well, compared to the model where design and execution are combined. Contracts and agreements are more open to discussion and modifications in the former models. This complicates the ease of coupling between the components and requires additional time for deliberation and agreements. On the other hand however, the order place has more freedom and influence in the design process.

The most important difference among all the models is the way coordination and control takes place. In the traditional contracting model the order placer takes care of the coordination. The SBR analyses showed that this is often very complicated and requires a lot of expertise. The order placer may decide to form a team to coordinate the entire process (building team) or hire a management contractor to support him. In all cases responsibility remains in the hands of the order placer. In general we may speak of customer-oriented coordination. The order could also decide to outsource coordination, control and even responsibility entirely to an external party, such as a contractor, a joint venture or even a predetermined brochure plan. In this case we can speak of process-oriented coordination; not the customer’s requirements is leading, but the primary design and fulfillment process. As an obvious effect, module autonomy is highest in the models where design and execution are separated.

We observe that the modularity features of the organizational models do not all point in the same direction. The building team, for instance, consists of distinct, loosely coupled and autonomous modules, but the interfaces between these modules are far from standardized and the clarity of mapping between functions and components is not very high either. These discrepancies may be subject to change in the experimental project

Summarizing, by ‘averaging’ the modularity features we come to the following typology:

Most modular: Traditional and Management Contracting
Average modular: Building Team and Design & Build
Least modular: General contracting and Brochure plan

### 6.7.3 Supply chain modularity within *Gewild Wonen*

With a more important role for the customer in the design phase of a house, we may expect some changes in the chosen organization model to occur, compared to regular housing projects. The following section reflects a number of opinions and findings in the *GW- case*.

The most often chosen organizational model – in fact, all sub-projects chose this model – is the building team. According to one of the order placers this is by far the most obvious model to choose, because you do not know exactly what you will build beforehand. Contracting, via tenders, as in the traditional approach, is therefore impossible. Approximately 70% of the respondents on the final questionnaire agreed with this order placer by means of question 4.1 of the final questionnaire ('Cooperation in a building team is the most obvious type of cooperation in a project such as *Gewild Wonen*', see appendix 6). In some cases, an extra member is added to the building team: the broker. In these cases, the team was divided into two different groups: a technical group and a commercial group. The broker was sometimes assisted by a professional sales aide, who offered the customers support and guidance during the design process. The majority of the respondents agrees with the statement that the structure and functioning of the building team had been changed significantly in the *GW-project*. The distribution of the answers for both statements is illustrated below in figure 6.15.

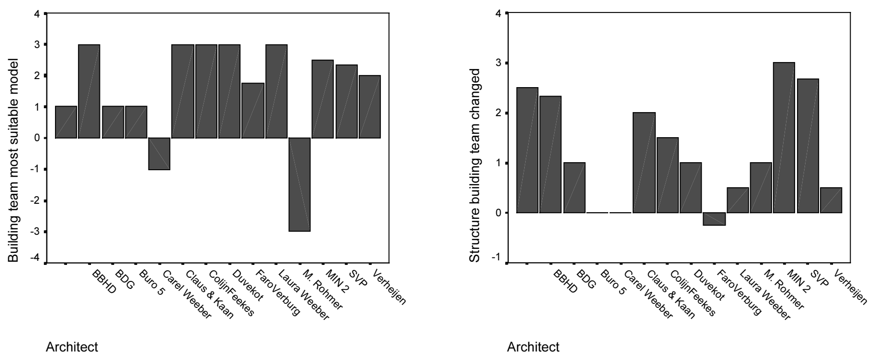



**Figure 6.15: Distribution of answers to questions 4.1 and 4.2**

The responsibilities within the building team however, largely remained distributed the same among the members and most participants still worked with their "standard" partners. Most building teams had to meet more frequently, due to the new and experimental character of the project. Many of the architects had difficulties finding the right balance between large customer freedom, with the need to need work numerous design details, and drawing efficiency, with several choice options already fixed beforehand. Normally, they were used to the standard phases of a building project (see section 6.6.1). After a preliminary design, where floor plans and fronts are designed, the final design is made, where the plan is worked out in more detail. Subsequently, the builder's specifications and drawings are constructed and the deliberation with the contractor is started. The decision-path towards the end becomes smaller and smaller. However, in the *GW-project* the final design of the plan already takes place before the floor plans and fronts are known, because at that moment there are no buyers yet. In other words the architects already know the detailed outlook of the plan, but the general structure is unknown. This requires numerous assumptions to keep several options open. This causes a lot of extra work, because various details are worked out in detail, which may never be built at all. Figure 6.16 below illustrates the difference between the two approaches.

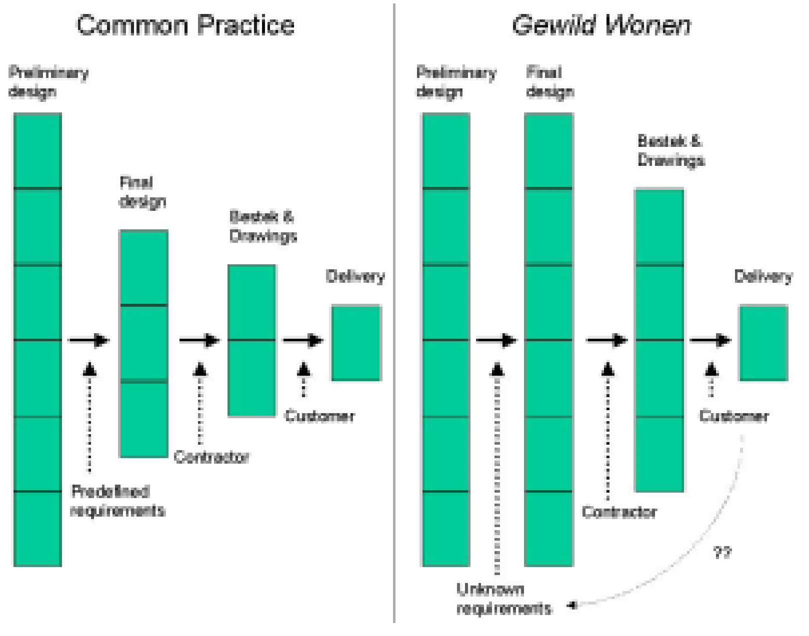



**Figure 6.16: Difference between regular design phase and *Gewild Wonen***

Where normally, the path from preliminary design narrows towards the end – more and more design options (each square in figure 6.16 represents a design option) are cancelled – in *Gewild Wonen* the path stays wide for a longer time. Where in regular housing projects the step from preliminary design to final design is based on predefined requirements (the so-called Program of Requirements, see section 6.6.1) and decisions made by the developer (order placer) and the architect themselves, they now have to wait for the customer to decide. Only the contractor often narrows the path a little for technical reasons. Because in *Gewild Wonen* the customer still enters the process relatively late – the project had already been going for about a year when deliberation with the customer commenced – the narrowing of the path occurs quite late in the design phase. In many sub-projects, the consequence of this was that the architect and the developer together already decided to limit the number of choice options in the final design.

A possible solution to this problem would be to involve the customer early in the process. This however, is often practically infeasible. To include the customer in the building team was not considered an option by the majority of the participants. The issues discussed in the building team are far too technical for this customer. Therefore, another option would be to set up an extensive database where all the final design details of all components are stored already. This would also support the design of more standardized interfaces, i.e. contracts and procedures, in the building team. We saw in the previous section that for the building team no such standard procedures exist. Using standard CAD programs, cost information systems etc. could provide these standard interfaces and avoid many of the problems that were encountered in the project. ICT infrastructures focused on these issues are subject of discussion in section 6.9.

The opinions differed with respect to the moment the builder should be present in the building team. Arguments were heard to include the builder as soon as possible: "We decided to involve a typical 'catalogue builder' (see section 6.4.2) early in the building team and to use his experiences with woodframe building." Others argued for entry as late as possible: "Our contractor was only involved in the second phase of the project. Main reason for us to do this is that we do not want to be limited to one particular building system, in which the builder is specialized. The contractor only served as advisor in the earlier phases." Developers who do not build themselves often choose the latter model. It makes them more flexible in their own opinion.

A number of developers – approximately half of them – incorporated both functions in their own company; they are both developer as well as builder. With respect to the combination of a builder and developer in one organization, an architect mentions the following: "In this *GW-project* the relation between builder and developer might change. It will partly depend on the size of the company, but most of the times such a company has a strict separation between both divisions. Their largest problem often is the exact place of the boundary. In reality, this is often not very strictly determined, while one knows each other very well, so that both business units get intertwined. The builder is normally responsible for calculations, the quality, the costs and technical issues. A developer mostly takes care of financial affairs and profitability."

Where the architect to some extent questions the effectiveness of such a combination, the builder/developer himself is far more positive about this integral approach: "It is our advantage that we are a developing builder or vice versa. In general we can develop our project more efficient than a single developer. A developer is always confronted, at the end of the developing phase when he is looking for contractors, whether his ideas are in fact technically feasible. We do not have these kind of problems; both functions are integrated in our company. During the development phase we already think about the technical feasibility of the project."

Another builder/developer adds: "We are forced to work with sub-contractors. Beforehand, as many agreements as possible are made, also about prices. You need to use the creativity and knowledge of these parties wherever you can. In return, you allow them to produce certain modules. However, we do not want to produce exclusive modules. If you do this, and outsource the production to one single party, then the competition disappears and you limit yourself too much."

Our final questionnaire further shed light on the design of the supply chain of each of the sub-projects. The questions:

In the *Gewild Wonen* project we searched for a suitable supplier for each individual house component.
In regular housing projects we use far less suppliers than in the *Gewild Wonen* project.
For a project such as *Gewild Wonen* it is - even more than normally - necessary that the role of order placer and builder are strictly separated.
The responsibilities within the building team were differently distributed compared to regular housing projects.
In this project we worked less with our "fixed partners" than we normally do.

together make up the variable SUPPLY CHAIN MODULARITY. The resulting Cronbach alpha from a reliability analysis on these five items was 0.8360. A high value for this variable thus indicates a high supply chain modularity with the following features:

- Direct relation between house component and supplier
- More suppliers than normal
- Strict separation between order placer and builder
- Different distribution of responsibilities than normal
- Worked less with 'fixed' partners

The following figure, 6.17, depicts the distribution of the degrees of supply chain modularity among the different sub-projects.

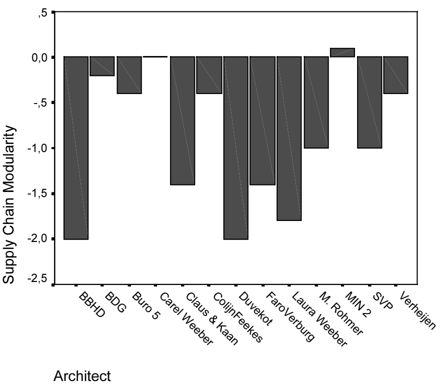



**Figure 6.17: Supply Chain Modularity per sub-project**

We observe that for all sub-projects the degree of supply chain modularity is quite low. This is not surprising as the items in fact indicate a *change* in supply chain modularity with respect to regular, normal projects. While all sub-projects make use of the building team, which in itself, as we have seen in the previous section, is a very modular model, with clear and distinct tasks and responsibilities and loosely coupled components, it is not expected that the change will be very high. As we compare the projects with each other we observe that several projects, such as the ones from BDG, Bureau 5, Carel Weeber, Colijn & Feekes and especially Min2 have higher modularity values than the other projects. The lowest scores come from BBHD, Claus & Kaan, Duvekot and Laura Weeber. We further see that the variable Supply Chain Modularity correlates with the following questions/statements:

- We had to diverge from favorite building method (correlation coeff. 0.359; significance 0.093)

- Supporter-infill systems – introduced by Habraken – are very suitable for *Gewild Wonen* (corr. 0.435; sig. 0.062)
- We had to develop one or more new building techniques for our house design (corr. 0.402; sig. 0.052)
- The majority of the consequences of increase customer influence can be solved by so-called *more/less work* solutions (corr. –0.358; sig. 0.094)

These correlations indicate that indeed an increase in supply chain modularity requires at least a significant change in process structure and chosen production methods. Highly modular process techniques, such as Habraken's supporter-infill method prove to coincide well with modular supply chains (see section 6.13.1 for more information on this method). Standard and maybe old-fashioned solutions such as *more/less work* may no longer work in these cases, as illustrated with the negative correlation between both variables.

Summarizing, the following table is presented which describes the change in supply chain modularity for each of the *GW-subprojects*. We have used the modularity features of the previous sections to indicate the most important changes in supply chain modularity caused by the *GW-project*. By analyzing the changes in the organizational model, caused by the *GW-project* with more modular product and – sometimes – process structures, we are actually able to analyze and validate our propositions with respect to three-dimensional modularity.

| Design type | Project name | Architects | Change in supply chain modularity |
|---|---|---|---|
| **Variant** | Choosing creatively… | Claus & Kaan | No change |
| | Living as only you would like | BBHD | Decreased: tighter coupling |
| **Core** | Living in a block-house | Duvekot | Decreased |
| | The islands: Flexible watervillas | UN Studio | … |
| | The Growing House | Laura Weeber | Decreased |
| | The reflection | BDG | Slight increase |
| | Personal house & garden style | Faro | No change |
| | Do you want the main part? | Bureau 5 | Slight Increase: coupling loosened |
| | Personal housing | Carel Weeber | Increased: more distinct, task-specific parties |
| | The Kettlehouse | M Rohmer | No change |
| | Slimfit rental houses | SVP | No change |
| **Sectional** | Pioneers in the Polder | Colijn&Feekes | Increased: more distinct, task-specific parties |
| | Multiple Choice | ArchitectenCie | Increased: multiple suppliers for key components |
| **Free** | All hands on deck | Verheijen | Slight Increase: more distinct, task-specific parties |
| | Free-style living | Min2 | Increased: more distinct, task-specific parties |

**Table 6.19: Process modularity of different housing projects**

Summarizing, we learn from these descriptions that most building teams have become more modular, although the effects are not very large. In the earlier comments we saw that especially the frequency of meeting and the division of the team in a technical and a commercial part were the most notable changes. Both changes do not directly indicate a higher or lower degree of modularity according to our definitions. In sections 6.12 and 6.13 we will further reflect on the concurrency and correlation between the three dimensions product, process and supply chain and discuss whether the sub-projects tried to make the connection between them more explicit.

## *6.8 Clockspeed*

We will use this section briefly discuss the concept of clockspeed for the building industry. Based on the work of Fine, we distinguish between three areas and developments to analyze the clockspeed of the housing industry: technological, organizational and product-variety. We base our analysis of the clockspeed of the housing industry on a number of publications and on the answers of the respondents in our case study. In general it was found that the building industry has quite a slow rate of development, a low degree of industrialization and long product life-cycles. It has grown very slowly, it develops very slowly and it is very cost-determined.

The industry is quite stable with respect to product variety; the houses that were built 25 years ago are still built today. The need to build numerous houses, to meet the high demand for newly built houses, caused a very low degree of variety in product design and development. Especially in the 70's all Dutch newly built houses looked alike. Only in the last couple of years is one looking for more diversity and variety in house design and do we see a slight increase in the clockspeed of the organizations closest to the customer: property developers, estate agents and housing corporations. They feel the increasing pressure from customer for more influence and customization of houses.

The Dutch building industry has quite a slow rate of development and long product life cycles. An architect, involved in the *GW-project*, notes: 'You might say that the building industry is in fact slow and ineffective. This is caused by the fact that a house must last so much longer than any other product and it is produced in quantities of only one. A couple of years ago, a lot of houses were built in an inefficient manner, based on the thought that houses only had to last for 15 years. Now, this idea is changing and the preferred life-time of a house has become 50 years, mainly because of durability.' Another architect adds: 'The building industry is completely different from other industries. It has grown very slowly, it develops very slowly and it is very cost determined. It has a low degree of industrialization, with a strong focus on craftsmanship and all deviations from normal practice are very expensive.'

For instance, many people in the building industry view the automotive industry as an example of how things should be organized; the technological advances of this industry are on a higher level than those of the building industry and the degree of personification is better, it is claimed. The question then arises how this was caused. First of all, the building sector is a very special type of labor, with its own typical backgrounds. Not only does this refer to the fact that the production of building is very location dependent, contrary to the production of, e.g., radios, washing machines or t-shirts. It also refers to the specific cultural character of the industry; a house is bought, financed and experienced in a very different manner than other products. These factors could explain the low degree of industrialization of the industry.

Furthermore, the housing industry is strongly regulated; the national government has a great degree of involvement in the industry. A number of years ago the government came up with the idea of building numerous expansion suburbs, just outside city centers, which they called Vinex locations, to meet the growing demands for houses. These locations however, are largely criticized because of their low quality, minimal customer influence and inferior facilities, such as public transport, schools and cultural events. Furthermore, a number of governmental regulations exist, which to a large extent limit the influence of the customer in these areas (Keers et al. 1999):

- Destination plan: an urban design which determines the preferred future destination of pieces of land
- Land policy: concerns the prices and emission of plots
- Building plan: an extensive set of technical rules concerning the building of houses
- The prosperity commission: deals with the external appearance of a house, whether it fits in its environment etc. (for this reason also called beauty commission)

In general, we may conclude that the clockspeed of the Dutch housing industry is quite low. The low degree of industrialization and the numerous regulations limit the degree of influence of the customer on the design. Moreover, they also influence the structure of the business networks in the building industry, which we will observe later on in this chapter.

## *6.9 Use of ICT*

### 6.9.1 ICT Potentials

The building industry may be considered as one of the great potentials for the introduction of ICT within and between organizations. As we saw before, the building sector can be described as quite stable and conservative with respect to new technologies, with a strong focus on craftsmanship. Innovation rate is low and little money is spent on product development and research. This is obviously a perfect soil for the possibilities of ICT, preferably in combination with modularity and standardization.

Nowadays, the building sector is still mostly focused on incremental process improvements. Radical product innovation would mean a new way of production, focused on large-scale production, flexibility and industrialization (Stroeken 1994). In some sense, the building industry still functions as the automotive industry in its early days. In this section we will discuss some of the possibilities for use of ICT in the housing industry in general and the *GW-project* in particular. We first focus on the possibilities of ICT to support the customer during the design process (6.9.2), followed by an overview of how ICT could support the architect. Section 6.9.4 then deals with ICT to support the contractors and builders, in particular by means of EDI. In section 6.9.5 we elaborate on the use of ICT in the *GW-project*.

### 6.9.2 Customer support

Houses are very complex products, which require advanced expert knowledge to design them. Architects take care of the design and they are assisted by many professionals, such as engineers and constructors who calculate costs, safety, ventilation and the likes. When part of this design process would be handed over to the customer, this would mean that the customer would either need to have this knowledge himself or source it in from somewhere. Often, the latter form is chosen. Expert knowledge like this could be offered in various ways, via face-to-face communication, documentation and textbooks, scale models etc. Another option could be to utilize ICT for this purpose.

An important role for ICT could be to support the customer – the buyer of the house – in designing his own house. That is, the technical, design side could be simplified for the customer by offering him advanced design support technologies, such as Computer Aided Design technology or visualization techniques such as Virtual Reality. On the other hand, the customer may be supported in finding his way through the very complex process of finding a piece of ground to build a house on, getting all required permissions, finding skillful architects, builders etc.

The most straightforward option is to use the Computer Aided Design tools, used by architects and engineers themselves, and to redesign them as such that – relatively inexperienced – customers can work with them. One of such systems is ArchiCAD, developed by Graphisoft, which is in fact used in one of the sub-projects of *Gewild Wonen* to support the customer during the design process (the project *Pioneers in the Polder,* developed by Colijn & Feekes and GBV Zondag). ArchiCAD addresses every facet of the architectural process in one software package, from design and documentation to communication and collaboration. The key to ArchiCAD is that it creates a digital model of the real building: the Virtual Building. All of the building information is stored in a central project database, and from this integrated 3D model one can derive:

- complete plans
- sections and elevations
- architectural and construction details
- quantitative data for bills of materials
- window, door and finish schedules
- building management information
- renderings, animations and virtual reality (VR) scenes.

Among ArchiCAD's most useful innovations for the *GW-project* is its ability to generate VR scenes without any additional software or special knowledge. Customers can experience a virtual tour within their own house and freely navigate among spaces. Several VR files can fit on a single floppy disk or be emailed or downloaded from the Internet[19].

Subsequently, the Internet can play a significant role in the design support process as well. A program such as ArchiCAD may be integrated within a website to come up with some sort of housing-laboratory, where 3-D building drawings are presented, together with prices per building module. Another step would be to link these visualizations with the database of the suppliers of these building modules for immediate ordering. Even more, the site could offer an overview of expected monthly costs (including energy, maintenance, etc.), dependent on the choices made by the customer.

Another well-known and successful feature of the Internet is community building. A chatroom or discussion platform could be created where (future) buyers could come together to exchange ideas or where future neighbors could coordinate and synchronize

[19] Another less serious, but very funny, example of an architectural design program useful for "architecture-dummies" is the PC-game The Sims. In this game, the player can design houses, decorate them with numerous items and even more, raise a family within the house. Originally the program was destined to become a architectural design program, but during the development process the programmers decided to put people in the house as well and turn it into a – very successful – game.

their requirements to ensure the total image of the neighborhood. At the moment, obviously due to the experimental and explorative character of the project, none of such sites are actually existent, but it may be expected that they will soon be developed.

### 6.9.3 Designer support

The end product of the building industry is obviously the house or building. All information exchanged eventually should lead to the delivery of this product. In this case, we speak of PDI. With PDI it concerns the exchange of data between designers and builders, about building designs or products such as doors, windows and walls. It merely concerns functional and technical specifications. PDI is based on the so-called STEP standard. Although the STEP project started in 1984, its objectives are currently still being discussed, due to its dynamic nature. Focus has shifted from data exchange to data sharing, and along with the conceptual developments, implementation aspects came more and more into the scope of the project (van Leeuwen & van Zutphen 1994).

The highest level of PDI is achieved when one works on the basis of product models (information modeling), instead of mutual exchange of documents (data modeling). PDI developments have already shown the immense problems of defining standards for exchange of data. The development of product model based information systems (PMIS) actually involves much more. First, information modeling is more complicated than data modeling, since information includes semantic knowledge about data. Second, where PDI leaves the data processing systems intact, in PMIS we need to redefine the information system itself, which includes redefining organizational models, task models, user models, etc. This will have an impact on activities and structures within organizations.

For these purposes it is necessary to establish a definition of what information constitutes a complete definition of a product; to gain acceptance of the developments of such a standard information model; and to improve implementation of computer technologies for support of these developments (Wilson 1993). Unambiguous documentation of products requires a large amount of information on the basis of standard norms, which are still hardly available. The development of PMIS is characterized by an ill-defined problem field, a lack of resources and generally accepted standards, and a lack of dedicated information-modeling tools.

PDI-exchange on the basis of product models requires a substantially different way of working and communicating in the sector. Each party retrieves the information it needs from the central database. After processing of the information by, for instance, the architect, the newly gained information is sent back and entered into the database. Large-scale introduction of PMIS will most likely lead to a more effective network (van Leeuwen & van Zutphen 1994).

### 6.9.4 Contractor support

EDI in the building industry deals with direct computer exchange – without human intervention – of business information such as order placement, order confirmations and invoices. This mostly takes place in the execution phase where goods and equipment are transported to the building site. EDIFACT is the global standard for the syntax of EDI messages, but this does not mean that it is clear exactly which documents need to be exchanged. This requires further industry-specific agreements. A couple of years ago, Edibouw and Hibin developed standards for information exchange between contractor and manufacturer and the building material organizations respectively. Nowadays, they operate together as HCP/Edibouw. Efficiency advantages of direct EDI can be found in costs, error and lead time reduction. Furthermore, the logistic process can become more effective and more enduring relationships are likely to emerge.

The interaction between building companies and manufacturers offers the greatest potential for the use of EDI, for electronic processing of orders, due to the higher frequency and size of the orders. For smaller contractors EDI and other forms of E-Commerce will most likely only become profitable when they can communicate, via a standardized, central system (such as the Internet), with other parties in the building network. This is caused by the low interaction-intensity compared to the high investment costs. This is one of the reasons HCP/Edibouw was founded. For information exchange between procurement organizations and building markets EDI is well suited as well. The exchange between these network nodes mostly takes place within a large building market corporation (such as Gamma, Praxis of Formido). The highly intensive interaction is almost completely carried out with EDI. The procurement organizations function as wholesalers for the building markets.

Despite the promising advantages of the use of ICT in the building processes, the adoption rate is still fairly low, especially among small and medium-sized companies. The ministry of economic affairs in the Netherlands initiated a campaign in early September 2000, entitled 'The building industry goes digital' (www.debouwgaatdigitaal.nl). This campaign, a common initiative by ten branch organizations has the objective to stimulate the use of ICT in the building sector and its supplying industry. By newsletters, media-attention, instruction meetings and a service center at least half of the 20.000 Dutch organizations, which are active in the building industry, must *know* what ICT can mean for their business processes. A research carried out by USP Marketing Consultancy in Rotterdam shows that most of the business processes nowadays are still supported by traditional means of communication. Although the use of Internet is increasing, it is merely used as replacement of the fax (e-mail) or a brochure (website). Activities such as on-line procurement or sales are hardly done online.

### 6.9.5 The Use of ICT in the *GW-Project*

By means of our survey and in the face-to-face interviews we asked the participants about their use of ICT and the possibilities for ICT in the building industry. Far from all stakeholders in the *GW-project* make extensive use of ICT, either during the design or during the execution process. They saw however, great potentials for it, illustrated by the responses to the statement: 'Nowadays, many mistakes are made because parties do not supply each other in time with the correct information' (see appendix 6). The following figure illustrates the answers graphically.

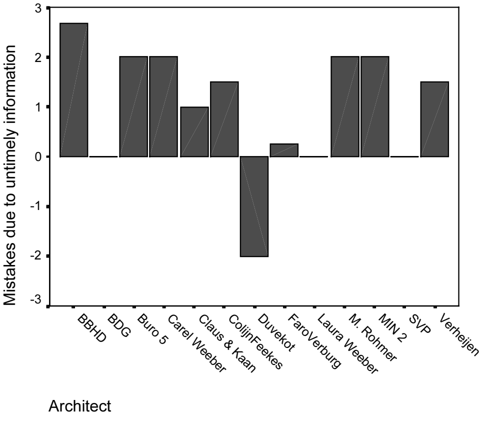



**Figure 6.18: Distribution of answers to 'Mistakes made due to untimely information'**

Only Duvekot/Rehorst strongly disagrees with this statement. Subsequently, we identified two main variables from the final questionnaire, i.e. ICT UTILITY and ICT PROSPECTS. The ICT UTILITY variable is constructed from the questions

It would benefit a project such as *Gewild Wonen* if we would could use a (computer) information system that would transfer each customer choice directly to our contractors and suppliers.
Without advanced information systems *Gewild Wonen* will never be applied on a large scale because building companies are not equipped not handle the large amount of (customer and process) information.
The more prefab elements in a design, the more important the role of ICT during the preparation and finishing of the design.
Buyers want to know the financial consequences for each of their choices; an automated cost-information system is therefore indispensable.
*Gewild Wonen* is that complex mainly because the amount of information (about costs, choices, planning etc.) that needs to be processed, increases a lot.
Information systems already play an important role during the design and execution phase of most building projects.

The newly defined variable has a Cronbach alpha of 0.8150, which indicates that the scale is well-defined. The ICT PROSPECTS variable is constructed from questions:

We expect that in the future the Internet will play a significant role in the housing market.
With respect to cooperation and coordination of the actors in the building process, ICT could play a much more important role than currently and thus improve the efficiency of the building process.
Investing in ICT applications is requisite to make projects such as *Gewild Wonen* profitable.
The party that in the future will make the best use of ICT, will play a leading role in consumer-oriented building.

This variable had a Cronbach alpha of 0.8214. The distribution of the answers per sub-project is depicted in figure 6.19a and b.

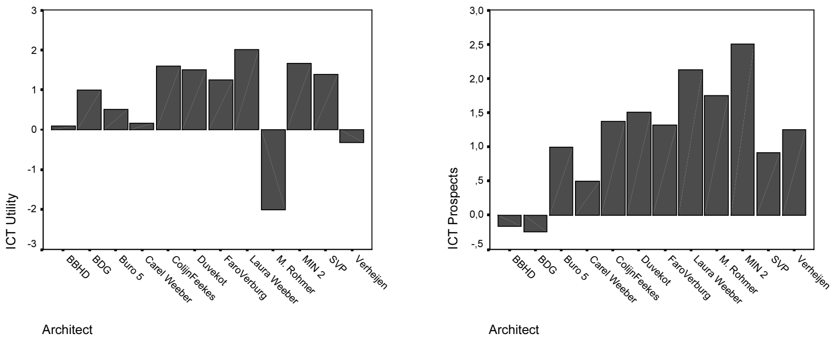



**Figure 6.19a&b: ICT Utility and ICT Prospects**

One should note that above figures do not illustrate the *actual use* of ICT within the different sub-projects. They only indicate agreement with the *potentials* for ICT. The actual use, as mentioned above, is quite low within the building industry in general and *Gewild Wonen* in particular. The remainder of this section discusses one particular builder/contractor which actually is quite advanced in using ICT and uses ICT for coordination and communication, i.e. Nijhuis[20]. Nijhuis developed a method – called Trento – in which ICT plays a crucial and central role. The builder, located in Rijssen, noticed – not only in the *GW-project*, but also in other projects they built – that with the increased variety in house designs, lay-out variants and other choice options, the amount of customer-related information 'exploded'. Within the current, traditional network and information infrastructure this increased amount could hardly be processed anymore. This subsequently led to a decrease in performance of the network. Nijhuis tried to change this trend by automating its primary processes. This should enable the specification of more customer-oriented house designs. Dedicated software was required to support this, such that all information could be entered in one single information system. Not only could all of the information then be presented in a user-friendly format to the customer (see section 6.9.2 for more on customer design support), the primary processes could profit from it as well. The following figure – designed by Nijhuis itself – illustrates this.

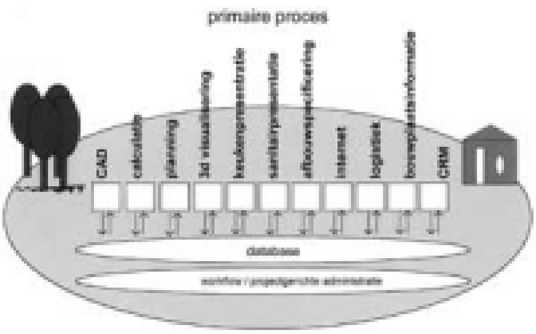



**Figure 6.20: The Trento framework of Nijhuis**

[20] Nijhuis is involved as builder in the project *Personal House and Garden Style* of FARO and Bemog.

Nijhuis uses AutoCAD for this purpose, a software system largely similar to ArchiCAD. Approximately half of all organizations in the building sector use some sort of CAD system, according to the people from Nijhuis, of which 80 to 90 percent uses AutoCAD. Just as Microsoft Windows has grown to become the standard operating system for PC's, AutoCAD has become the standard CAD-system and thus offers easy exchange of documents and files – a prerequisite for efficient communication within networks.

With the capabilities of the CAD program in mind, Nijhuis could start to reorganize their primary processes, focusing on increased customer influence on the design. This led to the development of the Trento method. Trento is a modular concept, i.e. the buyer can select from numerous project-independent elements to configure his own house. Furthermore, Nijhuis realized that they needed to control the entire process of development in order to actually realize their Trento concept. This was a large change compared to the traditional development process – i.e. the building network – where many stakeholders have a say in the actual design of the house, except for the buyer. In other words, quite paradoxically, in order to increase the influence of the end-customer of the network, they had to increase their own influence within the network.

During the development of the Trento method it turned out that AutoCAD could help Nijhuis in gaining control over the development process. The distributor of AutoCAD – C&N Solutions – understood Nijhuis' requirements and proposed a solution on the basis of AutoCAD and another program, called Automanager-Workflow. At the start of the development, is was Nijhuis' desire to organize, control and, where needed, change the drawings of suppliers. AutoCAD included a drawing-control system which enabled this, leading to the development of a so-called house-configurator with, among other things, a 'where-used' functionality. Thanks to this system Nijhuis could indeed strengthen its controlling role and increase its competitive power.

With an upgrade of the AutoCAD system, developed in close cooperation with Nijhuis, the Trento method was further improved. For instance, the layout of the house could be largely automated. This means that all architects and draftsmen work with the same, standard layout, thus allowing for easy exchangeability and automatic conformity with Dutch CAD regulations. Other parts of the design process were standardized as well, in the form of standard AutoCAD library objects, the so-called X-Refs. They can be reused over and over again. The objects are organized hierarchically; some objects always come back and other objects are very specific. With these objects a house is designed, according to the requirements of the customer.

Because of this standardization, Nijhuis is able to offer far more different houses, without the need to work out every individual design in great detail on the drawing table. A problem that many other architects faced in the *GW-project*, which often led to a decrease in choice options for the customer.

Nijhuis is not planning to limit their Trento to the design phase only. The design phase is only one part of the entire primary process (see section 6.6.1). In the case of a global method, which covers all parts of the primary process, this could lead to an integrated information system. This system collects all information from start to finish of a project.

Such a system could be integrated with ERP and workflow systems. According to Nijhuis, the AutoCAD functionalities should and will be leading in the choice of such a system.

## *6.10 Building industry-specific variables*

During the case study, numerous remarks were made by the respondents about relevant issues within a project such as *Gewild Wonen*. These issues were not explicitly included - nor will they be - in our research framework, but they definitely influence the success of mass-customization of houses and the use of modularity. We will summarize them below.

### 6.10.1 Governmental regulations

The Dutch housing industry is a strongly regulated industry. Each house built in the Netherlands has to comply with the so called Building Resolution - a large collection of detailed, technical rules for all aspects of a house. It concerns issues such as ventilation, safety, usability, health and energy economy[21]. Each individual house design has to be approved on the basis of this resolution. For the *GW-project* in Almere this causes great difficulties while every house built will be unique in itself and therefore, formally, needs individual approval. The governmental institutions responsible for compliance are thus far unable and unwilling to approve the designs as a whole, i.e. judge the entire modular system instead of each individual variant. This means that either a buyer will need to specify his choices in a very early stage or the architect will need to work out every variant of the system in detail. The latter option is often too labor intensive, resulting in a decrease in possibilities for the customer.

### 6.10.2 High location-dependency of houses: the privacy-factor

The privacy-factor is defined as the requirement that a particular house should not interfere with or hamper the privacy of the people who live in the neighboring houses. This requirement strongly decreases the degree of freedom a house-buyer has in designing his or own house. The architect, who designs the modular system, has to take this into account. An example where this factor is of great importance is the location of the house on the plot. Some of the developers initially decided to give the customer full control over the exact location. However, during the design phase they decided to remove this choice option. A developer stated: "We think this option in the end may be impeding sales. We found out that this option may be advantageous for one buyer, but when you cannot make clear to another buyer where the house of its neighbor will be built, then you lose your customers. Furthermore, removal of this option enables us to start building the houses in an earlier stage; we can already commence with placing the foundation. Therefore, removal seems to be beneficial to all parties."

### 6.10.3 Coherence of the designs: total image of all designs

Finally, a house hardly ever stands on its own, independent and free of other houses and its surroundings. The beauty and image of a house is to a great extent determined by the way it fits into its environment. Moreover, the satisfaction of both buyers and the designers with the design strongly correlates with the way a certain individual house is part of the

[21] For instance, eleven different rules have been included concerning the size, height, location, steps and rail of a staircase.

total image of all houses and the area in which it is located. This means that individual customer freedom could hamper or decrease the total image of the houses built. It could, for instance, happen that one house strongly dissents with the surrounding houses, because of its different color, shape or layout. Obviously, not everyone worries about this, but most of the architects involved in the *GW-project* tried to include some repetition and standardization in their designs to ensure unity in total design. The level on which this repetition took place, strongly influenced – and often limited - the freedom for the buyer. An example – from the project *Do you want the main part?* - may illustrate this.

During the finalization of the initial design a small conflict arose between the developer and the architect. According to the developer, the 'formwill' of the architect was too big and therefore, the freedom for the customer too limited. Within the original design the freedom in selecting the modules was too restricted by the architectonic image preferred by the architect. The architect preferred a U-shaped house, but the developer did not want the buyer to be limited by U-shapes only and let the customer decide on the final shape of the house.

## *6.11 Network Performance*

### 6.11.1 Multi-perspective measurement

The performance or effectiveness of a business network is a difficult variable to operationalize. In general, an organization or network is *effective* if it achieves the desired end (Jarillo 1988). Very little theoretical work has been carried out that deals with issues of network outcomes and effectiveness (Provan & Milward 1995). Much of the work emphasizes network-level properties and structures. The critical issue however is, according to Provan and Milward, the effectiveness of the entire network, not whether some individual actors that are part of the network do a better job than others in providing a particular of the network product or service, delivered to the end-customer.

Provan & Milward (1995) do also admit that actual assessment of network effectiveness is extremely problematic. In the case of an entire network of organizations, the degree of effectiveness will probably be considered differently by different stakeholders (Provan & Milward 1995). They themselves operationalized effectiveness using a multi-measure, multi-perspective methodology designed to assess the overall well-being of severely mentally ill clients collectively served by the agencies that make up the health and human service delivery system in each of the US cities investigated. They identified three different groups: the clients themselves, their families and the clients' case managers or therapists, based on the belief that these three groups would have the most complete understanding of client outcomes, although each might have a somewhat different perspective (Provan & Milward 1995:8). They originally hoped to develop a single measure of network effectiveness, combining the perspective of the three groups, but the multiple constituency approach resulted in multiple views of effectiveness.

In line with the views of Provan & Milward, we follow a multi-perspective approach as well. The following stakeholders are identified:

1. The initiators of the project: the city of Almere

2. The other relevant stakeholders and participants in the project, such as designers, developers, builders and suppliers.
3. The end-customers, the users of the products or services at hand: the buyers and occupants of the houses built.

### 6.11.2 Project Initiators

When the *GW-project* commenced in 1999 each order placer, invited to participate by the city of Almere, had asked two architects to come up with a initial design. Almere then chose one of the two. The following criteria were used by the city to judge the entries for the project.

- Adaptability
- Freedom of choice for the occupant: exterior, interior, materials etc.
- Programmatic innovations and house typology
- Technical building innovations: e.g., need for foundations
- Privacy
- Variation
- Market orientation
- Parcellation / allocation of plots
- Unpredictability of eventual street image; the total picture
- Feeling of stature, standing for the buyer

### 6.11.3 Stakeholders

During our case study we were able to determine the judgement criteria and objectives of the stakeholders in the project, such as architects, developers and contractors. They were asked to indicate what, in their opinion, makes a housing project successful. Second, they were asked about the likely success of projects similar to *Gewild Wonen* in the future. Third, we asked them about the financial consequences of the *GW-project*.

Most reactions with respect to the success of a housing project in general can be categorized under “happy and satisfied customers”. Others were:

- successful sales / financial gains
- learning experience
- house needs to fit well in the environment
- house needs to be functional
- we want to build something special

All agreed that the success of the Dwelling of Demand project most likely can only be determined after 5 or 10 years when people have lived in their houses for a while. In this respect, we confronted the participants with the following statements.

*Projects such as* Gewild Wonen *will remain exceptions in the Dutch building industry.*
*The Netherlands are too densely populated to enable* Gewild Wonen *on a larger scale.*

Figure 6.21 depicts the distribution of the answers to both questions.

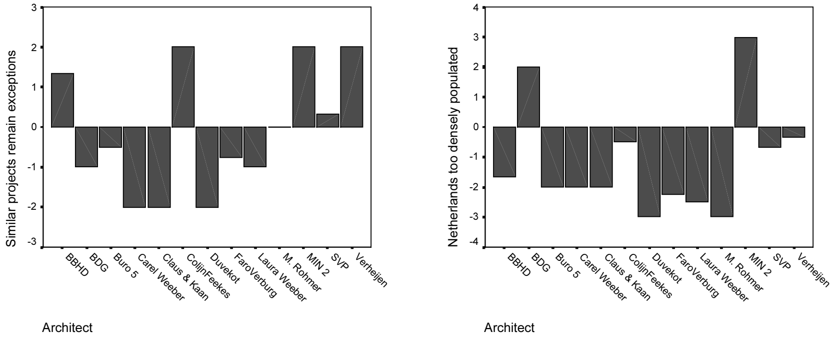


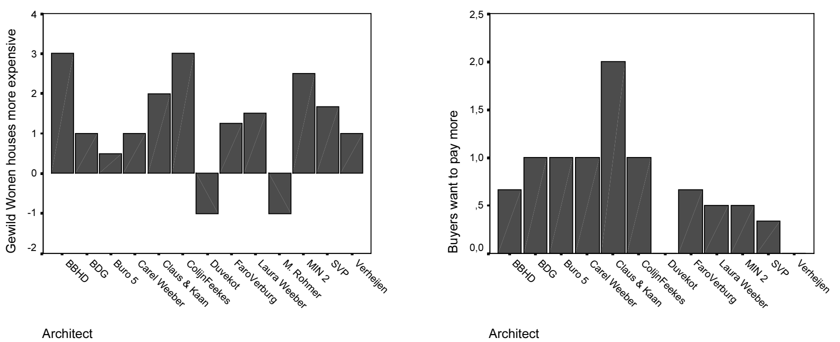

**Figure 6.21a&b: Future expectations**

Mixed emotions about the future prospects of projects similar to *Gewild Wonen*. Although the dense population of the Netherlands does not seem to be the biggest obstacle, about half of the respondents is not very optimistic about the viability of these projects. They think these type of projects will remain exceptions in the Dutch building industry.

We also asked them about the financial consequences of an experimental project such as *Gewild Wonen*:

Gewild Wonen *houses are always more expensive than regular houses.*
*Buyers are willing to pay more for more influence, such that the profit margins can stay the same.*
*Housing projects in the Netherlands are too small to make economies of scale on module level profitable.*
*The* Gewild Wonen *project was loss-making for us.*

The answers to these questions are shown in figures 6.22a to d.



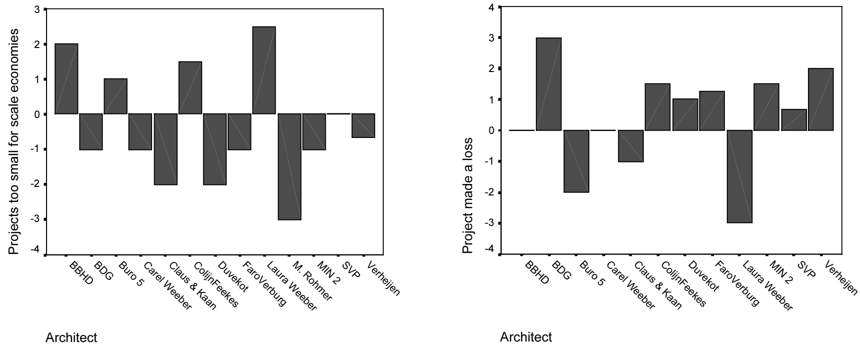



**Figure 6.22a-d: Financial consequences of the project**

Thus, we may conclude that the project was only profitable for a few actors. Still, the majority of the respondents expects that buyers are indeed prepared “to pay more, to say more”. Finally, it will most likely be difficult to save costs or make money by creating economies of scale on component level. In section 6.12 we will try to shed light on the question *why* some projects were loss-making, while others managed to make a profit. Is there, for instance, a relation between a three-dimensional modular design and profitability? First, we will take a look at another important performance criterion: customer satisfaction.

### 6.11.4 Customer satisfaction

As mentioned above, we wanted to find out whether the project lived up to its expectations with respect to the satisfaction of the customers, i.e. the buyers of the house. The Parasuraman et al. (1988) SERVQUAL model defines customer satisfaction as the difference between predicted service (what a customer believes will occur and considers of importance) and the perceived service (what a customer believes actually did occur). The satisfaction of the customers, and thus the effectiveness of the project perceived by the end-customers, will be the fit between their expectations and the actual outcome of the project in their view.

The SERVQUAL measurement instrument consists of five main categories:

- Tangibles – the appearance of physical facilities, equipment, personal and communication materials
- Reliability – the ability to perform the promised service dependably and accurately
- Responsiveness – the willingness to help customers and to provide prompt service
- Assurance – the knowledge and courtesy of employees and their ability to convey trust and confidence
- Empathy – the provision of caring individualized attention to customers

In total the SERVQUAL instrument consists of 22 items/statements to measure expectations and perceptions of actual performance. For our purpose we only needed to use one or two items of each category, while we added another extra category, i.e. Influence. This category consisted of four items. In total we thus used a 12 item instrument. All of these items can be found in appendix 7.

Figure 6.23 below shows for each of these items the 'satisfaction score', i.e. the difference between expectations/importance and actual service.

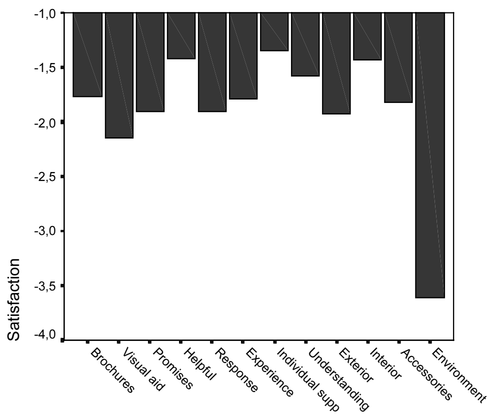



**Figure 6.23: Satisfaction scores for the 12 survey items**

Overall, we observe that the buyers are not very satisfied. Most satisfaction scores lie around –1.5. One item strongly rises above the others. This is the item that concerns the influence people can have on their living environment. The customers are thus not very happy about this influence; they would have liked this to be bigger. In the next section we will discuss the satisfaction score for each sub-project individually and subsequently combine these scores with the other – organizational – findings, such as customer disposition to participate, three-dimensional modularity and the use of ICT.

## *6.12 Validation of the propositions*

### 6.12.1 Introduction

After discussing the Gewild Wonen project, the question rises what we learn from all this about the modularity research framework of chapter 5. Where was modularity applied and where not? Why was it applied and how? Did we indeed observe the use of three-dimensional modularity and were these projects successful? What was the role of the customer in all of the sub-projects? Where did ICT come in and what was the impact of the projects on the back-office; the production processes and supply chains? Were their any analogies and concurrencies found between product, process and supply chain design and which of the sub-projects is likely to be most effective or successful? To what extent does did project confirm our propositions and to what extent can the theory on modularity help to explain certain developments? To answer these questions we will perform a cross-case analysis where we try to find common trends and similarities between the sub-projects, together with the biggest differences and controversies. The research framework looked as follows.

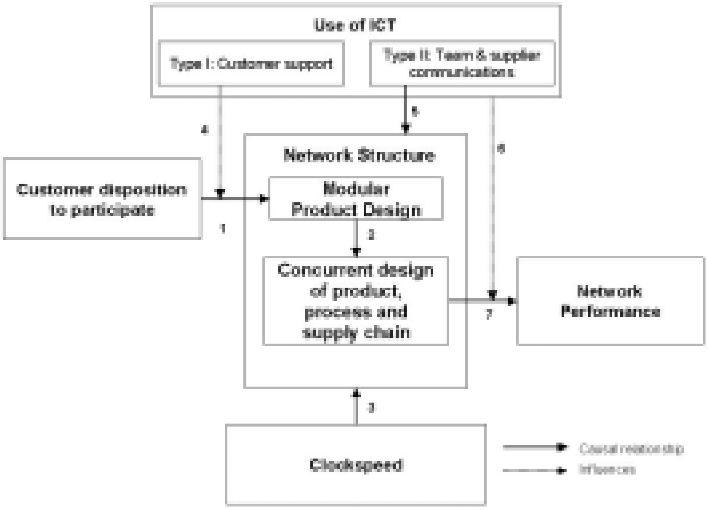



**Figure 6.24: Research framework**

The accompanying propositions were formulated as follows.

| | |
|---|---|
| P1 | *The higher the customer's disposition to participate, the higher the degree of product modularity.* |
| P2 | *The more modular a product design, the more modular process and supply chains will be designed as well.* |
| P3 | *The higher the clockspeed of an industry, the higher the need for a concurrent, modular design of the network will be.* |
| P4 | *The higher the use of ICT customer support tools, the stronger the relation between customer disposition to participate and modular product designs will be.* |
| P5 | *The higher the use of ICT tools for team and supplier communications, the more concurrent the three modularity dimensions will be designed.* |
| P6 | *The higher the use of ICT, the more effective a concurrently designed interorganizational business network will be.* |
| P7 | *A concurrent, modular design of products, processes and supply chains increases the performance of interorganizational business networks in general and a mass-customization strategy in particular.* |

We will try to validate these propositions by discussing the different sub-projects of *Gewild Wonen* individually and subsequently verify whether our research framework remains valid in each of these circumstances. Finally, we will draw the end-conclusions of this study followed by a description on how these conclusions can be further tested with a broader sample of businesses in different industries. The latter is the subject of chapter 7 where a survey is carried out among numerous organizations which are trying to (mass-)customize their products and services.

### 6.12.2 The Growing House – Laura Weeber and ABB

From the customer investigation we learned that buyers in this project are experienced in self-building of houses and are knowledgeable about architecture. They are experienced house buyers. The architect and the developer/builder also indicate that their buyer did have little trouble in designing their own house. The resulting variety in house is reasonably high.

Most customers chose this particular project not so much for the potential influence on the design, but merely for its location (close to the water and connection with the nearby lake) and general attraction. They are mostly unsatisfied about the problems with the water; the promised sluice won't be build shortly and people cannot moor their boats close to their houses. Buyers are satisfied though with the influence they had on the exterior looks of the house. The core house design thus lives up to its expectations; it is sufficiently modular compared to the customer's disposition to participate which is not very high, especially the willingness is fairly low.

This project combines a medium product modularity with a medium process modularity and a low supply chain modularity. They did not make many changes to their traditional organizational and supply chain structure. In other words they applied a concurrent design in three dimensions, although each of these dimensions individually is medium/low. In this case, this approach proved to be successful; the project was profitable and the buyers were satisfied. We find adequate support for our propositions in this project.

With respect to ICT, this project, like most other projects, does not extensively use ICT for process coordination and control or for customer support, but they do see the need for and usefulness of such applications. Although indirectly, this confirms our proposition of the use of ICT for concurrent design.

### 6.12.3 The Reflection – BDG and Verwelius

Once again, experienced customers in this project, who are mostly satisfied about the project. Only the support from the broker is judged as insufficient. The ability and willingness of the customers to participate is high. Despite the fact that the possible influence on the design could not be very high, due to the core design, customers are satisfied. Process and supply chain modularity are also at medium level in this project. In other words, just as in the other project, the concurrency between the three dimensions is apparent. The level of supply chain modularity for this project is a little higher compared to the previous project.

The project however, was loss-making. This is, most likely, due to the fact that according to the participants, the chosen building method was not very suitable for the purpose. The architect stresses that the industry needs to develop new, innovative building techniques that enable more customer freedom and design flexibility. Their is little support in this project for the view that ICT could improve efficiency of the building process. Summarizing we find medium support for our propositions. P1 and P2 are confirmed but the ICT propositions and P7 cannot be fully validated.

### 6.12.4 Living in a Block-house – Duvekot and Rehorst

This project is characterized by relatively many newcomers to the housing market. People with low ability to participate, who also indicated by means of the customer investigation that they found designing their own house more difficult than expected. In such cases, with low ability, support by the seller is desired. The stakeholders in this project however, hardly offered any support to their customers. The latter are very unsatisfied about this. They complain about the information they received about the project, fulfilling promises, answering questions and so on.

The supply chain modularity in this project is low. Hardly any changes were made compared to regular projects in the organizational model. Combining this low supply chain modularity with low/medium product and process modularity at least proved to be financially successful for the developers of this project. They managed to make a profit. The builder/developer himself states in this respect: 'What we are working on now, is how to translate the financial advantages of serial production into this project. We wonder how we can develop a generic design that is as broad as possible, such that it will be chosen by 99% of the customers.' In other words the builder was looking for as much standardization as possible and ways to standardize the interfaces between the components.

For this reason we find support for our proposition that a concurrent design increases firm performance, but an important additional remark has to be made. As said, the majority of the customers is very unsatisfied, mainly due to the inadequate guidance and support offered by the developer and broker. This means that a concurrent design by itself is not sufficient for successful customization of products. One has to pay attention to the customer's disposition to participate, i.e. his ability and willingness and variety in demands and subsequently guide the customer during the design process. This can be done by means of ICT support tools (as indicated in P4), but more 'down-to-earth methods', such as personal guidance, responsiveness and empathy are just as important as well.

### 6.12.5 Do you want the main part? – Bureau 5 and Hopman

This project is in its conclusions very similar to the Reflection project of BDG and Verwelius (see section 6.12.3). They both use a core product design, combined with medium process modularity (brick building) and supply chain modularity has slightly increased. The customer's disposition to participate is also quite high and customers are satisfied with the project. The only unsatisfied customers in this project are those who entered the project too late, when most of the building had already progressed too far to enable customer influence.

With respect to the link between customer influence and modularity, the architect mentions the following: 'When you choose for *Gewild Wonen* or some similar project, it is obvious to use a modular system. However, it is not the other way round. Sometimes a modular system can be too limiting; it is not really free, wild or spontaneous in itself.'

With respect to the process modularity of this design, the following was mentioned by the architect. 'The biggest difficulty during the design phase concerned the requirement that the house needed to be easy to dismantle, i.e. the need for separation and interchangeability of the modules. Constructively, this is very awkward, especially in relation to the foundations. Brick building is the building system of which the houses are the easiest to dismantle. In the United States one uses a lot of woodframe building; this is also very flexible. However, people in the Netherlands do not want to live in a wooden house.' Therefore, the architect and the developer chose to solve this problem by limiting the buyers a little bit, to avoid unworkable situations. The buyers had to agree on certain limits and they had to promise not to make certain adjustments for the next ten years or so.

In contradiction with the Reflection project, this project was profitable. Therefore, we find sufficient support for our propositions.

### 6.12.6 Pioneers in the Polder – Colijn & Feekes and Zondag

This is one of the two projects that have used a highly modular product design, defined as sectional. Our proposition P1 states that this is especially recommendable when customer disposition to participate is high. In this project, this is indeed the case. The customers are experienced house buyers, they love do-it-yourself activities, have earlier experiences with self-building of a house and are willing to participate in the design of their own home.

Organization-wise the project was very ambitious, especially because of the high product modularity and the potentially large customer influence. One of the most clear and disadvantageous effects of this approach was the fact that the time to complete this project was far too short. Because of the limited amount of time concessions had to be made to customer freedom and not all earlier-made promises could be fulfilled. The impact on supply chain structure was also quite large; the supply chain was more modular than the majority of the other projects. Such a change to the traditional structure obviously also requires additional time and subsequently caused the project to be loss-making.

With respect to our propositions we may conclude that a concurrent design, where all dimensions are highly modular is far more difficult to accomplish than a less modular design. The developers of this project do recognize the usefulness of ICT in this respect, but they were not able to set up a working ICT infrastructure for this project yet.

### 6.12.7 Personal House and Garden Style – Faro, Verburg and Bemog

Most buyers in this project do not really care much about participating in the design of their home. They have little to no experience with self-building. They mainly participate in this project because of the price of the houses, which is not very high.

Organization-wise the developers did not need to change very much. The supply chain did not undergo many changes. They do however use a highly modular building method. Most likely this is a too complicated and unnecessary method to use with, e.g., many prefabricated elements. Buyers do not ask for much influence, the builder could have used a less modular technique, with lower costs. This may have avoided the loss made in the project. The architect confirms this: 'This concept would be easier with a traditional building system such as brick building, with respect to the working-out, than with al the prefabrication that we want to do. This is mainly caused by the longer preparation phase, although time is won in a later phase. Prefabrication is more difficult because you now need to develop all possible extension variants. This means that you need to solve problems early in the design phase, which in a traditional building method could be postponed to the drawing engineer. The brick is more flexible in this respect.'

Summarizing, we find support for our research framework in this project in the sense that a concurrent design of all three dimensions might have worked better for this project. Customer disposition to participate is low, product modularity is medium and supply chain modularity is low. Now, the highly modular building method may have been somewhat 'overdone', what probably caused the lower performance. A less modular building method could have avoided the loss.

### 6.12.8 Multiple Choice – ArchitectenCie and Koopmans

This project is the other project that uses sectional modularity for their product design. The majority of the customers is satisfied, although they considered a little more difficult than expected. The support and guidance given by the developer was adequate and they were satisfied with the influence they had on the exterior of the house. The customer disposition to participate is medium.

Unfortunately, we did not receive responses to our final questionnaire, so some conclusions cannot be drawn, for instance, with regards to profitability of the project. Based on the interviews held with the stakeholders we may however conclude the following. Both product and process modularity are quite high in this project. The sectional product design is combined with a modular building method, called stealframe. It is an example of an open-building method, which is further explained in section 6.13.1.

With respect to the supply chain, the developer mentions the following. "We are forced to work with sub-contractors. Beforehand, as many agreements as possible are made, also about prices. You need to use the creativity and knowledge of these parties wherever you can. In return, you allow them to produce certain modules. However, we do not want to produce exclusive modules. If you do this, and outsource the production to one single party, then the competition disappears and you limit yourself too much." This is a typical example of using multiple suppliers for key components. No fixed, long-term agreements are made with one particular supplier. For each (set of) module(s) and each new project, one starts looking in the market for suitable sub-contractors and suppliers. The coupling between the supply chain modules thus becomes looser, and more distinct parties can be identified. The developer needs standardized contracts to enable this switching between suppliers, to shorten the process of price setting and making agreements as much as possible. All of these features are synonymous with a more modular design of the supply chain.

In other words we, once again, find strong support for our propositions on the usefulness of three-dimensional modular, concurrent design. This is further confirmed by the use of ICT for customer support during the design and the satisfied customers.

### 6.12.9 Personal Housing – Carel Weeber and ERA

In this project we find that the customer's disposition to participate is very low. Buyers have no knowledge of architecture, they do not like do-it-yourself work and are fairly new to the housing market. Developer ERA seems to have made a good assessment of its customers. They made the right decision in limiting the customer's influence on the design to some extent. A core product type design was chosen, with little influence on both the exterior and the interior of the house. The accent lied on the finishing and the accessories.

Surprisingly enough, this project exhibits one of the highest degrees of supply chain modularity of all sub-projects in *Gewild Wonen*. This means that we find no support for our concurrency proposition, while despite the imbalance of the three dimensions this project still may be regarded as a successful project. Customers are satisfied and financially, the project broke even.

### 6.12.10 All Hands on Deck – Verheijen and Proper Stok

In this project, the customers are very unsatisfied over many things. People had high expectations but they could not be fulfilled by the developer and the other participants. The main reason for the customers to participate in this specific project was the influence on the design. The willingness to participate was therefore high. Many of the buyers did not have earlier experiences with self building of a house and they expected to be guided during this process, which was necessary. Buyers had low ability to participate. Proper Stok however, failed in this respect. They did not fulfill their promises, they did not answer questions rightaway and were not always prepared to help.

Organization-wise, we see that the supply chain modularity is reasonably high. Combined with the Free design this was supposed to be advantageous, according to our research framework. Not only were the customers unsatisfied, the project also was loss-making for the stakeholders. It seems that the project was a little too ambitious for Proper Stok and that their organization and the surrounding organizations were not ready to accomplish such a project yet.

With respect to our framework, we thus see that although the three-dimensional concurrency is present and a modular design is chosen, this does not lead to better performance. Customer guidance, information exchange and good assessment of the willingness and especially ability of your customers are just as important.

### 6.12.11 Choosing creatively, living recreatively – Claus & Kaan and NCB

In general, the customers in this project are satisfied. Some disappointment is expressed about the lack of influence on the exterior of the houses, but mainly the project lived up to its expectations. Most of the buyers are newcomers to the housing market, with little experience. Most likely due to the simple, straightforward design of this project, people found the design process easier than expected. The support and guidance offered by the developer was sufficient for this purpose. The developer asserts: 'Maximal freedom of choice leads to indecisiveness. Therefore, we chose to offer only five basic types. Within each type two variants per floor are offered. The final step is the choice of a number of options and accessories. In our opinion customers are not able to deal with much more variants; he is benefited by a limitation of the number of choices to make and clearly defined guidelines.' One of the customers confirms the developer's expectation, by stating that 'choosing from five variants is *wild* enough.'.

Organization-wise this project confirms our proposition on concurrence between the three dimensions, where each dimension has a low degree of modularity. For instance, the chosen building method is concrete building, a technique with low process modularity. The hull can thus be built serially. As a consequence, staircases, for example, are all placed on the same location. Supply chain modularity is also low; little changes were made to regular practice. This can indeed work when customer disposition to participate is low. Customers are satisfied and financially the project is successful as well.

### 6.12.12 Free-style living – MIN2 and Credo

This project requires a lot from its customers with respect to self-building and knowledge about architecture and construction. Buyers indicate that they are indeed knowledgeable on this area. The biggest complaint from the customers is that suddenly most of the houses were fixed already because of the late start of the project. The delayed start was caused by a difference in opinion between the broker, the builder and the developer about the price setting of the houses. Because the major part of the house was not yet fixed, they could not agree on this. Unfortunately, this disagreement led to delay, which finally led to a significant decrease in customer influence.

Despite this drawback, the support and guidance is judged as sufficient. The willingness is there on the side of the developer, but the time was too short to solve all problems and still sustain sufficient customer freedom. The developer and the other stakeholder were not satisfied about the chosen building method either. This caused additional problems and costs.

The Free design type is combined with both relatively high process and supply chain modularity. This more or less confirms our proposition although product modularity of a Free design is not really applicable. These type of projects, with almost unlimited customer freedom are however hard to accomplish on a large scale. Much more difficult, for instance, than the previous project with low modularity in all dimensions. Not only does this demand a lot from the customer, i.e. large willingness and high ability, but a lot is asked from the organizers as well. Good support and guidance for each individual customer and a good connection with the underlying network structure. This structure should be adapted to the large variety in customer demands and be able to fulfill all these demand adequately. The importance of ICT in this respect is subscribed by the participants. That these type of projects, such as All Hands on Deck from Verheijen and Proper Stok, are still loss-making is rather not a surprise.

### 6.12.13 Living as only you would like – BBHD and WVA

This project is another good example, such as NCB's, of project with analogy and concurrency in all three dimensions, where all modularity levels are low. All other features for successful application of this structure are once again present. The buyers are newcomers to the housing market and have little experience and ability to design. BBHD did a good job in guiding these customers, who are satisfied about this.

Beforehand, the biggest concern for the developers of this project was the question whether the market would be ready for this concept. The housing corporation wondered how he should sell this unconventional design. This concern, for instance, led to a decrease in the number of facade options. From full freedom to only one facade method, with one material. Only the window frame area and the color remained optional. In terms of our research framework, this means that they expected low ability on the side of the customer to deal with this unconventional design, perhaps even low willingness to participate in such a project. Therefore, they limited the modularity, by decreasing the number of distinct components.

An additional complexity for housing corporations in general is the fact that they developed rental houses instead of owner-occupied houses. It is very difficult to involve a renter in an early stage of a new building project. Renters can be disappeared very quickly, which makes it difficult to make good agreements. Corporations need to stimulate this involvement within the limits of current policies and regulations, the so-called *Bouwbesluit*. In terms of our research framework, again this means they expected a lower willingness of the customer to be involved in designing a house.

The low 'scores' on ICT use can partly be explained from the fact that this project is not very complex with regard to information exchange. The stakeholder do not see much use in supporting the customer by means of ICT tools either.

## *6.13 Conclusions*

### 6.13.1 Introduction

In the building-related literature we already found that in the building industry concurrency between product, process and supply chain design has been an important topic for decades. In general, a strong linkage exists between the design of the product and the design of the production processes and the accompanying supply chain of participating organizations. The dimensions are closely related to each other. After the initiative phase, the architect comes up with the basic shape of his design; from an urban design point of view he designs houses with a rigid shape: connected, bricked, semi-detached or in blocks. In the context of our research framework, the architect determines the desired degree of modularity of the product. Already when choosing the shape, the architect needs to know how the houses will be built in a later stage. For instance, when the carcass is made of concrete, he needs to be sure that the hoisting crane can reach the building area to move the formwork elements during the construction. When the houses are built in a densely built area and no building site is available, one will often choose for building with prefabricated elements for the carcass, thus avoiding the use of large equipment. In addition, a building company constantly has to consider whether a design can be produced effectively with a certain building method. The fact whether the building company involved in the project is specialized in only one building method or can work with different methods is also of importance in that case. This already illustrates the close linkage between product, process and supply chain present in the building industry.

A typical example of the direct linkage and concurrency between product and process design in the building industry is the 'Open Building' method, which is, for instance, used in the *Multiple Choice* project, developed by Koopmans. By using the 'Open Building' method it is possible to produce different houses, while using the same hull. The hull is fixed, while the infill (inner walls, pipes and installations) can be done in different ways.

This system is also called the supporter-infill system. The idea behind the system is that a hull should last for at least 50 years, while the layout of a house can change many times within this period. This way of designing and building houses not only means that within a fixed hull, mutual different layouts can be made, which are easily replaceable. It also means that the variable building elements need to be manufactured and assembled, such that this easy replacement is indeed possible.

### 6.13.2 Three-dimensional modularity

With this in mind, we arrive at the *GW-project* and our findings there. The first finding in this respect is that the houses designed in *Gewild Wonen* were more modular than houses built in regular housing projects. Regular houses are most often integral designs, without much possibility for switching or separation of the modules. Most of the *GW* houses do possess this feature: they need to be expandable or changeable in the future and customers are able to select from a catalogue of modules in order to design their own house. Furthermore, most of the architects decided to introduce modularity on the level of the exterior, that is the most rigid level of house design, which determines the size and shape of the house. Flexible houses systems were designed instead of more integral fixed carcasses and floor plans, where the customers could only decide about the accessories of the house. The architects however did not go as far as designing already predetermined – and premanufactured - bedroom- or living room-modules[22]. The mapping between function and modules therefore was not fully modular like described earlier when discussing modular homes. Neither was the standardization of interfaces – the scheme by which the modules are connected. The building industry has not developed such standardization yet. As a consequence, the architects had to design every specific interface in detail.

In the case of the so-called Variant designs, the degree of modularity on product level was very low. Most of the houses however, were designed as follows: a core module containing all necessary facilities, such as entrance, staircase, storage rooms and the 'wet cells' (bathroom, toilet, pipes etc.), which could be further extended by the customer with other modules, selected from some sort of catalogue. We denoted these designs as Core designs. The more extensive this catalogue and the more types of modules it contained, the more modular the house design. Still however, the customer was limited in two ways: he could not choose anything that was not in the catalogue and he could not decide about the design of the core. Even when the fixed core was omitted, the customers were limited in choosing only from a fixed catalogue of options. This is always an inherent feature of modularity: it is limited in its granularity. In the case of a fully free design, such as in the *All Hands on Deck* and *Free-Style Living*, modularity is no longer useful, while modularity always limits freedom to the maximum number of combinations you can make with the available modules. A fully free design therefore is not benefited by modularity and vice versa. Continuing this line of reasoning, we could make a distinction between standard (one or a few fixed variants), limited-options (a limited number of options to choose from), mass-options (numerous options to choose from) and mass-customization (real, but affordable, freedom for the customer). One can compare the transition from discrete to continuous

[22] In the United States many 'modular homes' are built. They consist of three-dimensional, volume-enclosing units that are shipped as complete components from a factory and assembled on site. Essentially, a modular unit is thought of as a 'box', with all the internal or external features and finished completed in the factory, and only the connection to adjoining units and the hook-up of services are completed at the site.

with this distinction. It was learned from the customer investigation that even a few standard designs could be customized enough for particular customers, with a low disposition to participate.

In order to achieve modularity on the level of the exterior, manufacturing processes had to become more modular as well. That is, builders needed to use production techniques that actually allowed for building of these more modular homes. This meant that the more integral techniques, such as concrete building, were replaced by more flexible techniques such as woodframe building, assembly building and the previously discussed Open-Building technique. These techniques allow for late changes in design, while also making use of many prefabricated elements.

Finally, it was investigated whether the supply chains (or networks) became more modular themselves too. Did the construction of these networks become more flexible, allowing for switching between partners, more outsourcing of functions and more loosely coupled cooperations? The answer to this question is not straightforward. We already mentioned that all of the projects chose the building team as their organizational model. The building team already is quite a modular cooperation form – with clearly defined roles, strict division of responsibilities and relatively standard contracts and agreements.

The way the actors in some of the 15 sub-projects cooperated with each other really did not differ much from ordinary practice, i.e. housing projects with far less customer influence on house design. Partly, this could have been caused by the new and experimental character of the project, raising many problems that needed to be solved in close cooperation. Another explanation however, is the following, related to the concurrency between the three business dimensions. What we saw most of the times in the sub-projects was that whenever both product and process modularity were low, the supply chain did not require many changes compared to normal. This was in these cases very successful, at least when the customer's disposition to participate was also low. The projects designed by BBHD and Claus & Kaan are good examples as such. The stakeholders in these projects could rely on well-proven organizational structures and efficient and relatively low-cost building methods.

The project of Duvekot/Rehorst has mainly the same characteristics as the previous two and was financially successful as well. However, in contrast to the other two, customers were not satisfied. It turned out that customers with low ability, but with a high willingness to participate require adequate support and guidance during the design process. Only when this support is offered, and Rehorst failed to do this, may customers become satisfied as well.

There were two other projects that also exhibited close resemblance to the previous projects, i.e. the project of Faro/Bemog and the one from Carel Weeber with ERA. Both of these projects had to deal with a relatively low disposition of the customer to participate and solved this with a medium/low product design. Faro however, combined this with a highly modular building method. One could say that this was somewhat overdone and even unnecessary; the project was loss-making. The customers in fact did not require this. ERA on the other hand had a relatively high supply chain modularity. Still, despite this imbalance in the three dimensions, they made a profit and their customers were very satisfied.

We find reasonable support for our three-dimensional concurrency proposition in the 'medium zone'. Three projects were characterized by a medium customer disposition to participate and a medium product modularity. Laura Weeber/ABB however had low supply chain modularity and were still successful. This obviously contradicts our proposition. BDG/Verwelius and Bureau 5/Hopman had a medium level of all three dimensions and both had satisfied customers. The former however, made a loss, the latter a profit. Most likely, this may be explained by BDG's remark that they used a costly building method with which they had little experience.

Two projects demonstrated a high degree of modularity in all three dimensions: Colijn & Feekes/Zondag and ArchitectenCie/Koopmans. Such a modular, concurrent is more difficult than the previously described designs. In these cases, ICT is really needed, customers require support and guidance and the entire network must be ready for this. From our analysis it seems that the latter project was better equipped for this than the former. Koopmans, for instance, made use of ICT to support their customers and was really looking for multiple suppliers for their key components and use these suppliers' creativity and knowledge wherever they could. They also managed to make the project profitable and make their customers, with a high disposition to participate, satisfied. Colijn & Feekes with Zondag on the other hand did not manage this. Their customers were not satisfied and the project was loss-making. Probably they underestimated the complexity of the project and ended up in serious shortage of time. This subsequently limited customer freedom, which obviously was quite high initially due to the modular product design.

Finally, the two most ambitious projects came from Verheijen/Proper Stok and MIN2/Credo. A free design combined with high process and supply chain modularity, but still, both projects failed to live up to their expectations. Probably both projects were too ambitious: both the network participants as the customers themselves were not ready for this concept. The customers' disposition to participate, especially their ability, was in both projects too low to justify such an ambitious design. The developers themselves, just as Zondag, were not ready for this either. ICT infrastructures were not in place, customer support could not be offered and so on. To keep these type of houses affordable and feasible for the customer, one surely needs modularly designed supply chains, which make it possible to configure a cut-to-fit supply chain for each individual house design. In this case, if the property developer wants to support the customer in keeping the costs low, he needs to have access to a very modular network of actors. For each individual customer he needs to be able to set up a temporary, loosely coupled network of organizations, willing to participate in the design of this house. The difficulties in setting up such a structure can however not be underestimated.

### 6.13.3 Validation

Coming to the end of this chapter we return to our validation framework and ask ourselves what we can learn from the case study and subsequently what the stakeholders of the project and other researchers may learn from our analysis. We will start with the research framework by examining the propositions formulated in the previous chapter. In section 6.13.4 generalization of the results will be discussed.

P1 *The higher the customer's disposition to participate, the higher the degree of product modularity.*

P2 *The more modular a product design, the more modular process and supply chains will be designed as well.*

P3 *The higher the clockspeed of an industry, the higher the need for a concurrent, modular design of the network will be.*

P4 *The higher the use of ICT customer support tools, the stronger the relation between customer disposition to participate and modular product designs will be.*

P5 *The higher the use of ICT tools for team and supplier communications, the more concurrent the three modularity dimensions will be designed.*

P6 *The higher the use of ICT, the more effective a concurrently designed interorganizational business network will be.*

P7 *A concurrent, modular design of products, processes and supply chains increases the performance of interorganizational business networks in general and a mass-customization strategy in particular.*

With respect to proposition P1 we may state that when the customer's disposition to participate remains below a certain level of high ability and willingness combined with a high heterogeneity in demand then modularity of products is indeed recommendable. In general, the more heterogeneity of demand and the more eager the customer is to participate the more modular a product design may become. However, when demand is that heterogeneous and the customer very willing and able to participate, then modularity is no longer a solution. In the latter case, modularity limits the customer too much in his personal freedom.

We could refine proposition P2 by arguing that a concurrent design in three dimensions is easier to accomplish when all modularity levels are low, than when they all three are high. Most likely, the benefits of a highly modular structure are also higher. This brings us to proposition P7.

Proposition P7 should be refined by mentioning the following. A concurrent design in three dimensions is not always a *guarantee* for increased network performance. Several other factors must be taken into account, not only the fit between customer disposition to participate and modular product design, customer guidance, the use of ICT, but many other factors as well which are not specifically mentioned in our framework. A few building-specific factors are the 'privacy factor' and 'total image of all designs'. These factors were mentioned in sector 6.10. Other factors are 'being experienced with a particular network structure or method' (inexperience as we saw may lead to lower performance), time pressure and so on. *Ceterus paribus* (with all other factors being constant), we may say that proposition P7 still holds.

The clockspeed proposition P3 could not be validated within this case study, while it was carried out in one industry only. In general however, one can say that the housing industry has a fairly low clockspeed. As one of the architect notes: "The building industry is completely different from other industries. It has grown very slowly, it develops very slowly and it is very cost-determined. It has a low degree of industrialization, it is very laborious and all diversions from normal are very expensive." Nevertheless, we find many modular products in this industry and the concurrency between the three system levels is reasonable. The main conclusion concerning these two propositions is that they need to be further investigated in other industries which have different (higher) clockspeeds than the housing industry.

Although not many of the sub-projects used advanced customer support tools, proposition P4 remains valid. Many of the stakeholders agreed with the usefulness of these systems to increase the ability of the customer in participating in the design of the house. Multi-media systems, virtual reality and the Internet could be helpful in this manner.

Due to the very low degree of the use of ICT systems for team and supplier communication in the housing industry, we cannot draw any valid conclusions about propositions P5 and P6 at the moment. We did however indicate numerous possibilities how ICT could indeed support increasingly modular structures, both products, processes and supply chains. We illustrated these possibilities by discussing one particular builder, Nijhuis, and the different systems they use. Especially when modularity is high in all three dimensions it may be expected that use of ICT is indispensable. Further testing of this proposition in other industries is however required.

Further refinement and testing of our framework will be done by means of a business survey within numerous different industries. This survey will be subject of discussion in the next chapter.

### 6.13.4 Generalization of results

We will end this chapter by trying to extrapolate our case-specific findings to a more general level. This means that we will discuss the implications our findings may have on the building industry in general (see, e.g., De Volkskrant 2001, Building Business 2001). In this respect, our conclusions may be summarized by three keywords: communication, innovation and balance.

**Communication**

We have seen that communication was an essential part within each of the sub-projects and we also saw that quite often most mistakes were made in the communication process. Most importantly, the communication between the buyer on the one hand and the project developers, designers and builders on the other showed many shortcomings. Over the years, the Dutch building industry has become used to a very low level of communication with its buyers. The changed character of the *GW-project* and similar projects has forced the builders to enter into a dialogue with their customers and as such, try to live up to their requirements. We often noticed that these requirements did not so much concern the amount of influence on the design, but merely concerned issues such as keeping promises, empathy, understanding and timeliness. Those kind of issues were often neglected in the *GW-project*.

One of the most important causes for this lack of communication is the lack of a well-functioning customer contact point. Projects that did have a central information point that possessed sufficient knowledge and had enough time available for questions as well, performed better than projects that did not. In many of the sub-projects a traditional broker was appointed to take care of the customer contact process. However, in contrast with regular housing projects, customers did have more questions, often with a technical and detailed nature. These customers were often confused about whom they should contact. It was not clear for them who was responsible for what aspect of the project. They had many questions not only about their own house, but also about the house environment, the streetnames, the surrounding water, the rules and regulations, and they did not know who to approach for each of these issues. The broker, only used to handle issues such as prices and fixed housing features, was not able to answer all of these questions, nor to take care of finding adequate additional support. This disturbed many of the buyers as we learned from our customer investigation. One of the first and foremost challenges of the building industry will be to solve this communication problem.

Another remarkable finding was the limited cooperation between the different sub-projects. The stakeholders in each of the 15 sub-projects did not share their experiences about communicating with customers, solving technical problems or designing a suitable organizational structure with the stakeholders from the other projects. The city of Almere, as project initiator, could (and should) have played a more facilitating role in this. So, despite the fact that *Gewild Wonen* was an experimental project, with the objective to learn more about consumer-oriented building, participants do not behave accordingly. They choose individual competitive arguments above collective ones and thus were unwilling to share their knowledge with the other parties. In light of the ambitions of the industry to increase its customer-orientation, this may be considered rather strange. Sharing of experiences could improve the building industry as a whole, without disadvantages for the individual stakeholders.

The other more internally-oriented side of network communication was underdeveloped as well. The basis of a well-functioning business network as a whole is communication and information. Within the building industry, the adoption of ICT to exchange information between network partners is not very high. We investigated the many possibilities of ICT to improve building efficiency and reduce errors. An important role for ICT could be to support the customer – the buyer of the house – in designing his own house. That is, the technical, design side could be simplified for the customer by offering him advanced design support technologies, such as Computer Aided Design technology or visualization techniques such as Virtual Reality. On the other hand, the customer may be supported in finding his way through the very complex process of finding a piece of ground to build a house on, getting all required permissions, finding skillful architects, builders etc.

Two other ICT applications may be helpful as well: PDI and EDI. With PDI it concerns the exchange of data between designers and builders, about building designs or products such as doors, windows and walls. It merely concerns functional and technical specifications. EDI deals with direct computer exchange – without human intervention – of business information such as order placement, order confirmations and invoices. This mostly takes place in the execution phase where goods and equipment are transported to the building site. Efficiency advantages of direct EDI can be found in costs, error and lead time reduction. Furthermore, the logistic process can become more effective and more enduring relationships are likely to emerge.

**Innovation**

One of main reasons for the low degree of customer influence and variations in designs is the rigidity of many of the building methods used. Most of these methods do not allow for late changes in the design or variations within a housing block or even an entire housing area. The Open-Building method developed by Habraken (1961) did not receive much imitation and support. Only recently, it has received more attention in combination with developments such as IFD-building (Industrial, Flexible and Easily Dismantled building). Both Open-Building and IFD stimulate industrial manufacturing of building components and even entire buildings. The traditional execution on the building site can thus be replaced by easy assembly of these components. This modular approach to manufacturing in the building industry offers many advantages such as quicker and cheaper delivery of a building, more control of the process and better adaptation to changing demands of the market. The easy dismantling of the buildings further allows recycling and reuse of components.

Based on our findings we may certainly argue that these type of techniques deserve and require further research and development. They will be one of the cornerstones of customer-oriented building. Just as the automotive and computer industry developed industrial standards and techniques, the building industry needs to accomplish this as well. The 40 years of development of the Open-Building method and its spin-offs may serve as a good foundation.

**Balance**

When comparing the different individual sub-projects, the positive relationship found between three-dimensional business modularity and network performance was noteworthy. A concurrent design in all three dimensions often leads to better performances, at least when there is a fit between the customers' requirements and the network structure and capabilities. The willingness and ability of the customer to participate in the design of the product, and thus the network, is a very important variable that should be taken into consideration.

What we saw most of the times in the sub-projects was that whenever both product and process modularity were low, the supply chain did not require many changes compared to normal. This was in these cases very successful, at least when the customer's disposition to participate was also low. Some other projects demonstrated a high degree of modularity in all three dimensions. Such a modular, concurrent design is more difficult than the previously described designs. Developing the individual modules and assembling them requires knowledge and information about the individual modules and the way they interact with other modules. Baldwin & Clark (1997) stress that modular systems are much more difficult to design than comparable interconnected or integral systems. An organization must be technologically capable to manage this increased (informational) complexity. If not, using modularity will not lead the desired effects, such as innovation and customization, but instead will increase costs or decrease quality of the product or process. In these cases, ICT is really needed, customers require support and guidance and the entire network must be ready for this. It turned out that some projects were better equipped for this than other.

In other words the keyword here is balance. Balance between the customer's requirements and the organization's offerings. Balance between the three dimensions products, processes and supply chains. And finally, balance between the complexity of a project and the means available, such as ICT, to manage this complexity. In the next chapter we will see whether we find sufficient support for these findings in other industries as well.

# CHAPTER 7 SURVEY ON BUSINESS MODULARITY

## *7.1 Introduction*

The conclusions of the previous chapter already provided sufficient evidence to confirm the hypotheses formulated in chapter 5. For instance, the relationship found between modularity of products, processes and supply chains was satisfactory, together with the proposed relationship between a concurrent design and performance. In the previous chapter, we already elaborated on theoretical generalization of our findings in other industry sectors. In this one, we will discuss the actual empirical effort of further developing and validating our research framework in a broader setting. First, we will validate the applicability of our framework in multiple industries. This means that we will investigate the usability of the model's variables and its operationalizations and, if necessary, alter, add or remove some of these. Subsequently, we want to find out whether our model remains valid in these industry settings and if it doesn't, investigate why it fails to hold. In the end, this will help us in arriving at a research framework about business modularity, which has been developed, applied and validated in different business settings.

From a research perspective, a survey is the most suitable method to perform such an analysis. The exact question we want to answer is the following: How do organizations use modularity to support their (mass-)customization strategy? Such a question requires investigation of many organizations which are customizing their products. Case studies, experiments or other research methods are less suitable in this respect. Surveys are especially advantageous when "the research goal is to describe the incidence or prevalence of a phenomenon or when it is to be *predictive* about certain outcomes." (Yin 1994). The phenomenon we talk about here is modularity, the outcomes are (mass-) customization strategies.

This chapter describes the outcomes of a survey carried out to further develop the model and subsequently validate its hypotheses in a more general setting. The survey was carried out in the summer of 2000 and was sent to over 2000 mass-customizing organizations. Initially the survey was sent by e-mail only, followed by a paper-based reminder - including the complete survey itself - sent out to all organizations that did not respond to the on-line version.

In the next section - 7.2 - we will describe the survey process in general and we will further elaborate on the use of the Internet and e-mail as opposed to more traditional ways of carrying out surveys (regular mail and interviews). Issues such as non-response, sampling, creating incentives to participate and number of contacts are discussed in this section. Section 7.3 describes the instrumentation and data collection of our survey in particular. The constructs of the research framework of chapter 5 needed to be further operationalized into items, using the results of chapter 6. Furthermore, there is a detailed description of how the data was collected, which respondents were chosen and so forth. In section 7.4 the reliability of the items measured is discussed, using Cronbach alphas and principal components analysis. Based upon these results, some of the items may be eliminated. Section 7.5 then discusses the findings with respect to our research framework.

Statistical analysis is carried out, consisting of assessment of latent variables, reliability analysis of the operationalizations of the variables, correlations among the independent and dependent variables and possible causalities between them. The non-response is discussed as well. Subsequently in section 7.6 the research framework is refined based on the previous findings and cross-validated. The chapter ends with the conclusions and a discussion on the findings.

## *7.2 Research methodology*

Conducting a survey efficiently and effectively requires detailed planning. Many books have been written on survey design and the process of conducting a survey (Dillman 1978, Berdie et al. 1986, Converse & Presser 1986, Fowler 1988, Bradburn & Sudman 1988). The survey process is complex, time-consuming and often expensive. When designing a survey one has to be aware of many traps and pitfalls. These concern the social and cognitive context of the survey, the wording of questions, the length and specificity of the questions, the response categories, the visual outlook of the survey, its length, the grouping and sequence of the questions etc. All of these may influence the response rate of the survey and the reliability of the answers. In this section we will discuss the previous issues and describe ways to deal with them. We will especially focus on organizational (as compared to surveys aimed at individual consumers/respondents) and on-line surveys (as compared to paper-based).

### 7.2.1 Context of the questionnaire

Surveys are a special sort of social activity. They involve contact between people who typically are strangers to each other. More and more people receive mail and telephone calls from unknown persons, companies or institutions, who are inviting them to participate in some sort of inquiry or investigation. Therefore, it is important to design the survey as such that the relationship and understanding between the respondent and the researcher is as good as possible and that the respondent's frustration and irritation is reduced to a minimum such that the respondent is willing to participate. A good introduction and outline of the survey is essential for that matter. Respondents want to know - and are entitled to - the purpose of the research and the institutional setting behind it. It is to be expected that people are more willing to participate in non-commercial research than in its commercial equivalent. Respondents also need to know what will be done with the results of the survey research. Especially in business surveys, it could be an incentive for them to participate if they receive a copy of the results afterwards. Anonymity and confidentiality of research data is often a requisite, otherwise respondents will not share their (confidential) information with the researcher. Many of the previously discussed aspects may influence the answering of the respondents. Perceived sponsorship of the survey, the purpose of the survey, confidentiality of the data and the perceived professionalism of the researcher may all influence the answering behavior of the respondent. Many of these aspects may have different effects on the outcomes, but for the researcher it is essential to control these external variables as good as possible.

In business surveys an additional problem occurs. In regular survey researchers are confronted with type I (i.e. a false negative conclusion: rejecting $H_0$ (the null hypothesis) when $H_0$ is true) and type II (i.e., a false positive conclusion: accepting $H_0$ when $H_0$ is false) errors in testing of hypotheses. Business surveys however, also have to deal with type III errors, which may be even more important (Loebl 1990). These errors occur when the survey specifications are not met in the interviewing or measurement process and irrelevant information is obtained. For example in business surveys this may occur when collecting information on the wrong topic and/or interviewing the wrong person in a firm. When investigating small companies, finding the right person is less of a problem, but larger companies may be more awkward, especially when the survey topic requires advanced specialist knowledge on the topic. Further taking into account the fact that respondents often answer questions even when it appears that they know very little about the topic (Foddy 1993), makes this problem even more apparent. Interviewing multiple persons in one company and combining and comparing their answers may reduce the chance on type III errors.

Conducting e-mail surveys complicates things even further. The social context of e-mail can be described as a very fluid and superficial way of communication, where people receive many commercial mail (spam) from unknown persons. Conducting a survey via e-mail may therefore may be even more awkward. On the other hand, while more and more people get access to the Internet, e-mail surveys offer many advantages. It is much cheaper to execute, since it eliminates postage, printing and/or interviewer costs (Schaefer & Dillman 1998). They can be done faster as well, especially compared to (large sample) telephone surveys. Still, achieving adequate response rates with e-mail surveys may be more difficult due to the previously mentioned problems. Even more attention has to be paid to getting the contextual issues right.

All of these issues were taken into account as good as possible during the design of our survey on mass-customization and modularity. One can find the introductory text in appendix 8 and the questions related to type III error business surveys are discussed in section 7.4.1, as part of the demographic characteristics of the respondents. Note that the discussed type III error may be present, while our respondent database did not contain names of possible contactpersons. More on the latter issue can be found in section 7.3.1 on data collection.

### 7.2.2 Question wording and length

Language in general is in its essence ambiguous. Words may have different meanings, sentences may be understood and interpreted differently by different persons and people may differ in their level of understanding of a particular language. In ordinary conversation, respondents are able to ask for clarification and resolve any misunderstandings by simply asking for it. In surveys, where the conversation is between strangers and only one-way communication is possible, the possibility of clarification is lacking. As a consequence, respondents may interpret questions differently than intended by the researcher or they may even fail to understand the question at all. We won't go deeply into this aspect of survey design, but we will only briefly discuss some solutions and guidelines to avoid these problems.  One of these solutions is to avoid very complex questions, including difficult words and to avoid ambiguous words like any (could mean every, some or only one), just (may mean precisely, barely or closely) and fair (with meanings such as average, pretty good, plain or open). Negations (especially double or triple ones) in questions should be avoided as well, where people have trouble knowing what to do (agree or disagree) with these type of questions. One should also be careful in this respect when using the rating response option 'Disagree'; this can lead to a double negative when the item-question itself already contains a negation (For example: I do *not* like the teacher: Agree…Disagree). So called 'leading' questions, just as questions referring to two or more topics at once should be avoided as well. Finally, words with strong emotional or political content should not be used, while they can strongly influence responses to questions.

From the previous discussion it seems obvious that questions should be short and simple. However, on the other hand, one should avoid oversimplification of complex issues and superficial questioning. A balance needs to be found between the desire to simplify language and shorten the questions to increase comprehension and the desire to limit the possibility of multi-interpretation such that respondents are all thinking about the same thing when answering the questions.

### 7.2.3 Visual design and sequencing

A survey that looks sloppy and untidy will obviously decrease its response rate. People will get the feeling that the researcher has not taken the survey seriously himself and will doubt his professionalism. The survey must also be easy to read and easy to fill in. A good lay-out, using clear headings and explanation of the type of question is essential for that matter. When conducting e-mail or Internet surveys, one needs to be sure that the survey appears in the same format on all users' screens. People use many different e-mail browsers that may deal differently with certain formats and encodings. A plain text format avoids these problems, but this may look somewhat unprofessional. E-mail surveys may also be cumbersome to navigate, leading some individuals not to reply. Internet-based surveys, where the survey is placed on a webpage, can more easily be designed to appear similar on all users' screens, although more advanced programming options, such as java-scripts, forms and even graphics may still cause problems.

Another way to increase response is to use a logical and obvious sequencing of the questions. People will feel more comfortable answering the questions when there is a coherent structure behind it. Questions referring to the same topic or variable should be grouped together, thus telling the respondent in what direction the researcher is interested. While not all respondents may understand the meanings of the grouping, there will be fewer misunderstandings regarding the meaning of the questions.

### 7.2.4 Response categories and scales

Surveys may consist of closed end or open end questions or, what is most often seen, a combination of both. Both type of questions have their own (dis-) advantages. On the one hand, any given opinion is given less likely to be volunteered in an open-response format than to be endorsed in a closed-response format. On the other hand, opinions that are omitted from the set of response alternatives in a closed format are unlikely to be reported at all, even if an “other” category is explicitly offered. The latter is hardly ever used by respondents (Bradburn 1983, Schwarz & Hippler 1991). Furthermore, response alternatives in a closed end question have multiple and somewhat unexpected effects not only on the way respondents answer that question but on the way they answer subsequent questions as well. The response categories may, for instance, provide cues that aid in retrieving stored information, i.e. information that is not readily available to the respondent but that needs to be retrieved from memory. Respondents may be uncertain if information that comes to mind does or does not belong to the domain of information the investigator is interested in. Closed-response formats may take away this uncertainty, resulting in higher responses. Disadvantage of such closed-question formats may be that opinions are omitted from the set of response alternatives and therefore are not reported at all. Even worse, respondents can get irritated by the absence of their preferred answers and fail to complete the questionnaire. Table 7.1 below summarizes the differences between both type of questions (taken from Fobby 1993):

| Open questions | Closed questions |
|---|---|
| (a) Allow respondents to express themselves in their own words | (a) Allow respondents to answer the same question so that answers can be meaningfully compared |
| (b) Do not suggest answers:<br>• Indicate respondent's level of information<br>• Indicate what is salient in the respondent's mind<br>• Indicate strength of respondent's feelings | (b) Produce less variable answers |
| (c) Avoid format effects | (c) Present a recognition, as opposed to a recall, task to respondents and for this reason respondents find them much easier to answer |
| (d) Allow complex motivational influences and frames of reference to be identified | (d) Produce answers that are much easier to computerize and analyze. |
| (e) Are a necessary prerequisite for the proper development of sets of response options for closed questions | |
| (f) Aid in the interpretation of deviant responses to closed questions | |

**Table 7.1: The most important claims regarding open and closed questions (Fobby 1993)**

Theoretically, the order in which the response alternatives are presented may also influence the obtained results. Primacy effects, i.e., higher endorsements of items presented early in the list, as well as recency effects, i.e., higher endorsements of items presented late in the list, may be obtained. A third effect may be the contrast effect, where one item is preceded by an item that is more extreme on the dimension of judgment (Schwarz & Hippler 1991). In practice, it is almost impossible to rule out all these effects or even, to specify them. These topics are somewhat beyond the scope of this thesis and will not be further discussed, although we have tried to take them into account as good as possible while designing our survey.

With respect to scales, most users of numerical scales believe that the optimum number of points on a scale ranges from 5 to 11. Theoretically, the greater the number of points, the more powerful the scale is in discriminating, but respondents soon become unable to make fine distinctions between the points and start rounding off. Use of even scales is not recommended. Research by Schuman & Presser (1981) suggests that the distributions of positive-negative are similar and that the middle category does provide information on those who are really undecided.

### 7.2.5 Incentives and reminders

Finally, response rate can be increased by creating incentives to participate. Incentives could be rewards in the form of a monetary compensation, a coupon of some sort or a chance of winning a price when submitting. For business surveys these rewards will most likely be less effective. In these circumstances a summary of the research results may work better. One can decide to include the reward directly when sending the survey or only promise it when people actually participate. The former showed to be most successful (Church 1993) but requires a trust necessary for the social exchange to occur and is obviously more expensive. We refer to Fox et al. (1988) and Church (1993) who extensively discuss the effects of different treatments on response.

Sending one or more prenotifications, reminders and follow-ups also helps increasing response rate. A prenotification alerts people that the survey is coming, thus reducing the likelihood of an interested recipient inadvertently discarding it. Another reason could be that prenotification could establish legitimacy of the survey (Dillman 1978). Reminders and follow-ups in itself can be considered as a form of reward in the social exchange process (Dillman 1978) and they also serve to remind non-respondents that they have forgotten to complete the survey - a common reason for non-response.

## *7.3 Data collection*

### 7.3.1 Database

Our central research question requires respondents who are in some manner trying to (mass)customize their product or service offerings; they should pursue some sort of customization strategy. This means that they should present a significant degree of freedom to their customers in designing or constructing the products themselves, without the burden of extensive costs or delivery times. Obviously these type of organizations may be hard to find in practice. We initially conducted a search on the Internet, by using search engines such as Altavista, Google and Yahoo, together with a service offered by Netscape in combination with Alexa, which is called 'What is related?'. When visiting a website, Alexa shows a list of ten other websites or -pages that offer similar information to the website you are currently visiting. In this way, one can collect numerous organizations selling the same product or offering similar services. This search led to the first collection of customizing organizations[23].

In a later stage we came across a far more extensive overview of customizing firms at www.digichoice.com. Digichoice.com made an overview of thousands of companies in hundreds of different categories that are customizing their offerings. "DigiCHOICE was founded in September 1999 to meet the explosive growth in demand for customized products and services. Our co-founders realized that there needed to be a single location where businesses and consumers could go to find the custom products and services they required. So digiCHOICE was born to bring custom products and services companies from many different market segments together, under "one-roof". We at digiCHOICE believe that as the Internet continues its rapid expansion, more and more businesses and consumers from around the world will be demanding custom products and services. So we've

[23] An overview of this collection can be found at http://how.to/customize.

developed digiCHOICE to be the Internet portal where businesses and consumers can go to find the exact products they want - custom-made specifically for them." (taken from the digiCHOICE website).

We decided to use digiCHOICE's database of organizations and include them in our survey sample. The required names and addresses could all be found on the digiCHOICE webpages. It was decided not to inform digiCHOICE about our research for two reasons. First, we were afraid digiCHOICE might refuse cooperation and thus deny us the opportunity to carry out the survey on a large scale. Second, and most important, we found that digiCHOICE itself got their addresses from affiliate program services such as Commission-Junction, Linksynergy and Clicktrade. All of these are web site promotion and marketing organizations enabling web-based firms to increase their number of visitors, by featuring them on thousands of affiliate sites in exchange of a certain profit percentage. Therefore, we felt more or less free to use their database, although digiCHOICE will receive a copy of the research results.

As already mentioned, the database consists of thousands of organizations in hundreds of categories. The precise figures are shown below:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Number of main categories**[24] | 7: apparel, home&office, media, personal care, services, sports & other | | | | | | | |
| **Number of product categories** | 373 | | | | | | | |
| | Apparel | Home & Office | Media | Personal Care | Services | Sports | Other | **Total** |
| **Number of product categories within a main category** | 46 | 92 | 16 | 21 | 29 | 50 | 96 | **373** |
| **Number of different organizations per main category** | 263 | 677 | 53 | 70 | 220 | 213 | 547 | **2043** |
| **Percentage of organizations with a post-address** | 84.4% | 83.0% | 79.2% | 81.4% | 80.5% | 87.8% | 82.6% | **83.2%** |
| **Percentage of organizations with an e-mail address** | 91.6% | 90.4% | 88.7% | 91.4% | 96.4% | 93.9% | 88.5% | **91.0%** |
| **Percentage of organizations without post and e-mail address** | 2.2% | 2.5% | 1.9% | 5.7% | 1.4% | 0% | 2.4% | **2.2%** |

**Table 7.2: Features of DigiCHOICE database**

It can be seen that there is at least an e-mail address or a post address available for the majority of organizations in the database. We decided to include all of these organizations in our survey sample, while we wanted our sample to be as large as possible, to obtain the highest statistical significance and generalizability possible. We expected however that the media and services category would yield the lowest response rates (together with perhaps the miscellaneous 'other' category), because of our more product-based framework instead of services. It should further be noted that many of the e-mail addresses were typical sales or information addresses, such as sales@xxx.com or info@xxx.com. These addresses

[24] Note that we later on, during the analysis, changed these main categories into different ones, based on the responses we received. More on this in section 7.4.1.

would most likely be used for transactional issues only. Sending a survey to these addresses might increase chances on the previously mentioned type III errors, i.e. difficulties in finding the right person within a company.

The data collection process proceeded as follows:

| | |
|---|---|
| June 2000 | Carry out a number of pre-test face-to-face interviews to validate questions |
| June 28th 2000 | Send out e-mail survey (in html format) to all organizations with an e-mail address. |
| July 6th 2000 | Send out paper-based survey to all organizations without e-mail or incorrect e-mail address, but with postal address available (242 in total). |
| July 16th 2000 | Send out small e-mail reminder to 'e-mail organizations', referring to URL where entire survey could be found. |
| July 28th 2000 | Send out paper-based survey to 'e-mail organizations' who did not yet respond to e-mail survey. |
| Sept. 30th 2000 | Closure |

**Table 7.3: Plan of approach survey**

As one can notice we eventually sent both e-mail and paper-based surveys to the respondents. Mostly this was due to the relatively low response rate on the e-mail version. In the following section we will further elaborate on the (non-)response rate and the likely reasons behind these – somewhat low - rates.

## 7.3.2 Response Rates

The responses to each phase of our survey are displayed in table 7.4.

| | Apparel | Home & Office | Media | Personal Care | Services | Sports | Other | Total |
|---|---|---|---|---|---|---|---|---|
| **E-mail surveys sent** | 198 | 505 | 34 | 388 | 54 | 168 | 164 | 1511 |
| **Completed e-mail surveys** | 18 | 23 | 1 | 19 | 3 | 4 | 11 | 79 |
| **'Postal mail only' surveys sent** | 30 | 73 | 9 | 78 | 6 | 19 | 26 | 238 |
| **Completed 'postal mail only' surveys** | 2 | 2 | 1 | 3 | 1 | 2 | 0 | 11 |
| **Postal mail reminder survey sent** | 159 | 438 | 26 | 343 | 45 | 144 | 141 | 1296 |
| **Completed postal mail reminder** | 13 | 30 | 0 | 19 | 3 | 10 | 12 | 87 |
| **Undeliverable**[25] | 11 | 25 | 3 | 14 | 2 | 7 | 8 | 70 |
| **Total completed** | 33 | 55 | 2 | 41 | 7 | 16 | 23 | 186[26] |
| **Response rate** | 13.41% | 8.74% | 4.08% | 7.95% | 11.29% | 7.69% | 11.33% | 9.66%[27] |

**Table 7.4: Response rates**

[25] Surveys were undeliverable because either the e-mail address was incorrect or the postal address – or both.
[26] This includes 9 completed surveys from unknown respondents. These respondents were unknown because they sent their completed survey from an e-mail address not listed in our database.
[27] Response rate is calculated as the total number of completed responses divided by the sum of the initial e-mail and postal mail only surveys sent.

A total response rate of 9.66% is not very high, although many surveys suffer from low response rates. Causes for such a low rate may be found in the lack of the name of a contact person for each organization in the database, the technical problems with the e-mail form in html format or the content of the questionnaire itself. Some people responded to the researcher that the questions asked really were not applicable for their – often single person – business. Other, more generic problems, such as lack of time and the fact that part of the survey was sent during the holiday season may have impacted the response rate as well. One can observe that the highest response rates were found in the apparel, services and other category. The media category suffered from a very low response rate.

## *7.4 Instrumentation and reliability analysis*

In this section we will discuss the very important step of designing the survey: the variables, the items and the questions. The goal is to design the questions of the survey as such that the they adequately reflect the issues being studied and that is measured what you want to measure. This process is called operationalization or instrumentation. It is a matter of translating the constructs or variables into items and subsequently to design the question in order to measure the value of these items. The items are the basis of all surveys. The rigor that is required when developing items cannot be overemphasized (Rosenfeld et al. 1993). Any absence in rigor during item generation may result in later negative consequences that will not be correctable. Therefore, the researcher needs to clearly specify the topics he or she wants to investigate and he or she should have a clear idea about the information that is required about the topic. Due to the importance of instrumentation we will discuss this process in detail for our survey.

Furthermore, we will validate the instrumentation by discussing the results for each of the individual variables defined. This section is structured in line with the variables of our research framework together with a number of different control variables. For reasons of clarity we depict the research framework once again.

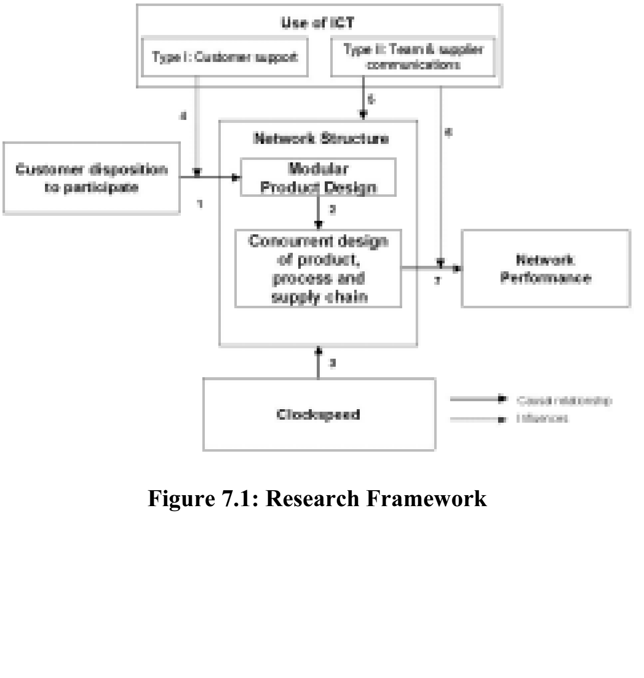



**Figure 7.1: Research Framework**

### 7.4.1 Demographic characteristics

Demographic characteristics (i.e. items that provide descriptive information about each respondent) are needed for almost any survey. In household surveys questions are asked about age, sex, and civil state of the respondent. Often these are necessary questions important for the underlying framework, but sometimes these questions are just used to make the respondent feel comfortable with the survey and its lay-out, before the "real" questions are asked. In business surveys these type of personal questions are of less importance while we are not interested in the respondent's private life per se, but focus on his organization and products instead. Therefore, a few questions will suffice, regarding the product or service an organization offers and its size. Other demographic information, like the country in which it is located, was already present in our database. Note that we also had the product category available in our database, but while many organizations were represented in multiple categories, we had to include a question about the product or service offered, to make sure all answers referred to this particular product or service.

Which customizable product or service do you offer? (In the case of multiple products, please choose the best selling customizable product/service your organization offers)

[From this point on, this product or service will be indicated as the 'product' in this survey.]

After analysis of the answers given to this question, it was found that the categorization made by DigiCHOICE was somewhat imprecise or too generic. For instance, Home & Office could be divided into more specific categories like construction, decoration and furniture. Beforehand, we could not have foreseen this obviously. Eventually, this led to the following categorization (with totals completed included), which in itself should induce more homogeneity within the categories.

| Category | Completed | Category | Completed |
|---|---|---|---|
| Apparel | 36 | Miscellaneous | 2 |
| Cases | 9 | Music | 8 |
| Construction | 16 | Printing | 11 |
| Decoration | 23 | Service | 6 |
| Food | 5 | Sports | 20 |
| Furniture | 18 | Tiles | 8 |
| Giftbaskets | 4 | Toys | 4 |
| Medical | 9 | Transport | 6 |
| **Total completed** | | | **185** |

**Table 7.5: Responses per new category**

Second, firm-size is an important variable in most business-surveys. Often, the size of a company is a determinative factor for issues regarding product design and development, supplier relationships and the use of ICT. Within our framework we especially expect larger sized firm to use a more modular supply chain design than smaller ones, while they are able to play a more dominant role within an industry segment and have more power over their suppliers. Since many of the organizations inquired produce a variety of customizable products, the survey was administered at business unit level.

How many people are employed in your organization?
o 1-9 o 10-49 o 50-99 o 100-499 o 500-999 o 1000+

How many people are employed in your business unit?
o 1-9 o 10-49 o 50-99 o 100+
[From this point on, this business unit will be addressed as 'we' or '(y)our'.]

As mentioned above, in business surveys the problem of type III errors, where the wrong persons are interviewed or irrelevant information is obtained, is of great importance. To avoid this problem it is recommended to include one or more questions which could help in identifying whether the respondent is indeed the right person to inquire and whether the person is in fact capable of answering the questions, which require specialist knowledge. For this reason is was decided to include a question asking how many people the respondent supervised. In combination with the size of the business unit, this should give some indication of the familiarity of the respondent with the topics inquired. It was decided that a too big a difference (e.g., BU size 50-99 and supervision 0-4) would make the response invalid[28].

How many people work under your supervision?
o 0-4 o 5-9 o 10-24 o 25-99 o 100+

It was found that the majority of the interviewed organizations are small or medium-sized organizations. Only around 3 percent of the organizations have more than 100 employees. Therefore, the size of the business units and the number of people under supervision of the respondent, follow a similar distribution as firm size. The following table depicts the exact data.

| Size | | | BU | | | Supervise | | |
|---|---|---|---|---|---|---|---|---|
| **Value** | **Freq.** | **Perc.** | **Value** | **Freq.** | **Perc.** | **Value** | **Freq.** | **Perc.** |
| 1-9 | 131 | 70.8 | 1-9 | 139 | 75.1 | 0-4 | 114 | 61.6 |
| 10-49 | 39 | 21.1 | 10-49 | 36 | 19.5 | 5-9 | 39 | 21.1 |
| 50-99 | 9 | 4.9 | 50-99 | 7 | 3.8 | 10-24 | 17 | 9.2 |
| 100-499 | 4 | 2.2 | 100+ | 1 | .5 | 25-99 | 11 | 5.9 |
| 500-999 | 0 | 0 | | | | 100+ | 2 | 1.1 |
| 1000+ | 2 | 1.1 | | | | | | |
| Missing | 0 | 0 | Missing | 2 | 1.1 | Missing | 2 | 1.1 |
| **Total** | 185 | 100 | **Total** | 185 | 100 | **Total** | 185 | 100 |

**Table 7.6: Firm size, business unit size and number of people under supervision**

We observe that the great majority of the responses come from small and medium-sized enterprises. This will obviously impact the rest of our findings, while we cannot effectively control for firm size, simply because the vast majority of the responding firms are small or medium-sized. The larger companies are under-represented.

[28] In fact, zero percent of the responses were considered invalid due to this rule.

### 7.4.2 Other control variables

**Type of customers**

The first control variable refers to the type of customers an organization. The reason to include this control variable is the following. It is to be expected that businesses know more about the products they are buying than individual customers. Therefore, we expect a higher customization sensitivity in business-to-business customization and thus a stronger need to use a concurrent modular design of products, processes and supply chains. The “both” category was omitted to force respondents to make a choice.

Customers who buy our product(s) are mainly:
o Private persons o Businesses
[From this point on, these will be addressed as the 'customer'.]

| | Customer Type | |
|---|---|---|
| **Value** | **Frequency** | **Percentage** |
| **Private** | 129 | 69.7 |
| **Business** | 50 | 27.0 |
| **Missing** | 6 | 3.2 |
| **Total** | 185 | 100 |

**Table 7.7: Type of customers**

The distribution of type of customers found, was as follows. Approximately 70 percent of the respondents are business-to-consumer organizations, where the remaining 30 percent sells their customized products on the business-to-business market. It was also found that the correlation between firm size and type of customer (1=private, 2=business) is 0.34 and significant at the .01 level. This means that larger firms are merely selling to businesses, while the smaller firms sell their products to private persons.

**Product complexity**

The third control variable is product complexity. During the case study in the housing industry we found that the more complex a product is, the more difficult it is for organizations to get their customers involved in the customization process. They somehow need to be supported and assisted while designing their product, either by an expert or by so-called expert tools or systems. Customers need to know more about the product and its (technical) design details before they can engage in designing themselves. Schilling (2000) argues that a customer must have understanding of how the components function individually and work together and interact. When products are very complex this may be more difficult for customers. Therefore, we expect a positive relationship between product complexity, the degree of support offered by organizations and the ability of customers to participate in the design of the product, at least in the case of successful customizing organizations. Furthermore, it is stated (Starr 1965, Van Hoek & Weken 1998) that the purpose of modular production is to decrease product complexity, while raising product variety to the customer. Although the latter statement will not really be tested in our survey, while we cannot determine a causal relationship that develops over time, we still may expect some kind of negative relationship between product complexity and product/process modularity (via the ability variable).

Instruments/items found in literature to determine the complexity of a product are:

- No. of printed circuit boards, product price, project staffing (Mendelson & Pillai 1998)
- Product price and number of different body features (in auto industry) (Clark & Fujimoto 1991)
- Number of functions performed by the product and the number of persons with different expertise involved in the development of the product (Griffin 1993)

All of these instruments are unfortunately too industry or product specific. We need a more generic measure.

In marketing research this variable is used as an important product characteristic to consider when performing buying-related research. The scale used by McCabe (1987) was composed of items based on factors identified by Hill (1972, 1973). Originally, the scale consisted of the following items: standardized vs. differentiated product, technically simple vs. technically complex, easy to install/use vs. specialized installation/use, no after sales service vs. technical after sales service and no consequential adjustment vs. large consequential adjustment. We slightly adapted this scale for our purposes. First, the fifth item (consequential adjustment) was omitted while during pre-testing this turned out to be a difficult item to comprehend by the pre-test respondents and second, an extra item was added, adequate for our purposes: configuration support required.

Using the rating scale shown below, please choose one number for each set of factors listed. Choose the number which best reflects your opinion of where your product falls on each scale.

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| A | Standardized product | o | o | o | o | o | Differentiated product |
| B | Technically simple | o | o | o | o | o | Technically complex |
| C | Easy to use / install | o | o | o | o | o | Specialized installation / use |
| D | No after sales service | o | o | o | o | o | Technical after sales service |
| E | No configuration support required | o | o | o | o | o | Extensive configuration support required |

The correlations found between the five items (Item A has been coded as Complex1, B as Complex2 etc.) are depicted in the following table:

| | Complex1 | Complex2 | Complex3 | Complex4 | Complex5 |
|---|---|---|---|---|---|
| **Complex1** | 1.000 | .290** | .087 | .168* | .133 |
| **Complex2** | .290** | 1.000 | .484** | .291** | .287** |
| **Complex3** | .087 | .484** | 1.000 | .326** | .478** |
| **Complex4** | .168* | .291** | .326** | 1.000 | .419** |
| **Complex5** | .133 | .287** | .478** | .419** | 1.000 |

** Correlation is significant at the .01 level (2-tailed)
* Correlation is significant at the .05 level (2-tailed)

**Table 7.8 Inter-item correlation for product complexity**

Factor analysis led to the extraction of one factor, explaining for 46.871% of total variance. Reliability analysis further confirmed the validity of the scale:

Item-total Statistics

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Alpha if Item Deleted |
|---|---|---|---|---|
| COMPLEX1 | 9.2184 | 15.6052 | .2909 | .7213 |
| COMPLEX2 | 10.2759 | 13.0564 | .5123 | .6363 |
| COMPLEX3 | 11.0402 | 13.0446 | .5422 | .6240 |
| COMPLEX4 | 10.5517 | 13.1736 | .4374 | .6711 |
| COMPLEX5 | 11.1897 | 13.6459 | .5497 | .6257 |

Cronbach Alpha = .7062

**Table 7.9: Reliability analysis**

Only deletion of the item COMPLEX1 (standardized vs. a differentiated product) could improve the Cronbach alpha. It was decided to do so while not only would this improve the reliability of the complexity scale, the item is also better suited for the variable Degree of Customization (see section 7.10).

When we use this scale, the following 10 products have the highest complexity:

1. Irish Championship Step Dancing Costumes
2. Amusement Rides
3. reusable protective shipping cases
4. ornamental metal products
5. recycled lumber
6. custom homes & additions
7. stringed musical instruments
8. golf equipment
9. custom homes
10. Custom Homes

Not surprisingly, we find the custom homes among the most complex products. This confirms our findings from the housing industry.

### 7.4.3 Customer disposition to participate

The previous research showed that the involvement of the customer is of great importance for the degree of modularity and/or customization that should be used. We divide customer disposition to participate into three different variables: heterogeneity of demand, customer willingness and customer ability. All three will be discussed here.

We searched the literature for useful instruments and tools which could help us in formulating the right items for above variables. Hart (1996) offers a number of diagnostic questions to assess a customer's customization sensitivity. These are:

- Are customers in your industry confused by mushrooming options and choices?
- Do unique and important customer needs vary by customer?
- After purchasing your products or services, are people customizing them on their own or through third parties?
- Would individualized products or services stimulate *primary* demand?
- What sacrifices do your customers make to do business with your company?

Another instrument is product understanding, originally used by Eliashberg & Robertson (1988) for measuring the perceived degree of customer time and effort required to appreciate a company's product introduction. Their instrument might be used to determine the customer's ability to customize the product. They used a 6-point Likert rating (from strongly disagree to strongly agree) for measuring the tree items:

- Customers must try the new product/service before they can really appreciate its benefits.
- It takes time until the customers can really understand the full advantages of our new product/service.
- Customers could readily engage in a product/service trial before buying our new product/service.

We have used these instruments to some extent to come up with a measure for the three variables. Note that we needed to determine the customer's disposition to participate from the perspective of the seller, i.e. the organization who offered the customized products. It was not possible to investigate the consumers themselves, like we did in the housing case of chapter 6.

A customer base with very identical, homogeneous customers with similar tastes and preferences surely does not require a high degree of customization nor a high degree of modularity. Schilling (2000) states that heterogeneous customer demand increases the modularity of a product. Two items were included in the survey that refer to the heterogeneity of demand and the diversity of the customers[29]:

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| We have a very diverse customer base (CDP3) | o | o | o | o | o |
| Our customers have very different preferences with respect to the features of our product (CDP6) | o | o | o | o | o |

Furthermore, the willingness of customers to participate in the design is another factor influencing the modularity of a product. A low willingness, due to factors such as lack of time, lack of interest, probably reduces the need for a modular design. Two items were used to measure this willingness:

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| Our customers are willing to participate in the customization process (CDP2) | o | o | o | o | o |
| Our customers increasingly want more influence on the design of our product (CDP5) | o | o | o | o | o |

Finally, the ability of a customer (also referred to as know-how or expertise) to participate in the design of a product is expected to influence the degree of modularity used. The following two items were used to measure this ability:

[29] Between parentheses the codes used in the survey analysis are depicted.

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| Our customers are quite sure about what they require in our product (CDP1) | o | o | o | o | o |
| It is easy for our customers to customize our product (CDP4) | o | o | o | o | o |

The items are correlated as follows (Spearman correlation is used while the items are ordinal measurements):

| | CDP1 | CDP2 | CDP3 | CDP4 | CDP5 | CDP6 |
|---|---|---|---|---|---|---|
| **CDP1** | 1.000 | .301** | .224** | .162* | .164* | .130 |
| **CDP2** | .301** | 1.000 | .433** | .285** | .433** | .380** |
| **CDP3** | .224** | .433** | 1.000 | .172* | .287* | .267** |
| **CDP4** | .162* | .285** | .172* | 1.000 | .213** | .144 |
| **CDP5** | .164* | .433** | .287** | .213** | 1.000 | .470** |
| **CDP6** | .130 | .380** | .267** | .144 | .470** | 1.000 |

** Correlation is significant at the .01 level (2-tailed)
* Correlation is significant at the .05 level (2-tailed)

**Table 7.10: Inter-item correlations for customer disposition to participate**

We can see that the correlation between CI1 and CI4 is not very high (0.162) and only significant at the .05 level. This could mean that both items together may not be measuring the same variable (in this case: customer ability to participate in the design process). We take a look at the questions themselves to determine the reason behind this low correlation.

CI1: Our customers are quite sure about what they require in our product
CI4: It is easy for our customers to customize our product

Perhaps, question CI4 was too ambiguous and caused the low correlation to occur. The 'easiness of customization' could have been interpreted as being due to the company's abilities and not so much as being due to the abilities of the customer. Therefore, it is decided only to add CI1 as to the ‘Willingness’ variable, which now consists of three items: CI1, CI2 and CI5. This new variable is defined as ‘Involvement’, which thus stands for the degree the customer is willing and able to participate. Reliability analysis of this new variable indicated a Cronbach alpha of 0.55, which is just sufficient.

### 7.4.4 Product modularity

One of the most important variables in this survey is the product modularity variable. It is the central issue in this thesis and the starting point of our analysis. Despite this importance it is also one of the most awkward and ambiguous variables. Many scientific and popular articles discuss the concept and its (dis-)advantages, however often without using a clear definition of the concept. Obviously, this complicates the measurement of the variable to a large extent. Nevertheless, we have to come up with an adequate measurement based on earlier research - discussed in chapter 5 - and our case study in the housing industry (chapter 6). Hopefully, this will lead to a more profound definition, useful for other researchers as well.
We indicated five different features of importance for the modularity of a product.

- Distinctiveness of components
- Loose coupling between modules; tight coupling within modules
- Clarity of mapping between functions and components
- Standardization of interfaces
- Low levels of coordination (components are self-organizing; coordination embedded in the architecture)

These features were combined into one single definition:
*A system is modular when it consists of distinct (autonomous) components, which are loosely coupled with each other, with a clear relationship between each component and its function(s) and well-defined, standardized interfaces connecting the components, which require low levels of coordination.*

This definition just as each of the five features individually proved to be hard to operationalize into specific survey questions, merely because the respondents would have difficulties in understanding what was meant. We thus decided to focus on the direct, visible consequences of product modularity and ask whether these consequences were valid for the product at hand. This led to the following items (coded as PDM1 to PDM6):

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| Our product can easily be upgraded or updated by our customers after they have purchased the product | o | o | o | o | o |
| The components we buy for our product easily fit together even if they are supplied by different firms | o | o | o | o | o |
| Our product consists of several distinct components, each with a clearly specified function | o | o | o | o | o |
| Our product has extensive "plug-and-play" functionality | o | o | o | o | o |
| You can split our product into many different parts after which you can easily put them back together without losing functionality | o | o | o | o | o |
| You can think of our product as a construction box consisting of various building blocks | o | o | o | o | o |

The first look at the (Spearman) correlations between the six items shows the following result:

| | PDM1 | PDM2 | PDM3 | PDM4 | PDM5 | PDM6 |
|---|---|---|---|---|---|---|
| **PDM1** | 1.000 | .078 | .231** | .299** | .244** | .138 |
| **PDM2** | .078 | 1.000 | .254** | .178* | .105 | .199** |
| **PDM3** | .231** | .254** | 1.000 | .391** | .216** | .371** |
| **PDM4** | .299** | .178* | .391** | 1.000 | .238** | .303** |
| **PDM5** | .244** | .105 | .216** | .238** | 1.000 | .444** |
| **PDM6** | .138 | .199** | .371** | .303** | .444** | 1.000 |

** Correlation is significant at the .01 level (2-tailed); * Correlation is significant at the .05 level (2-tailed)

**Table 7.11: Inter-item correlations for product modularity**

Only a few inter-item correlations are NOT significant. These are PDM1-PDM2, PDM1-PDM6 and PDM2-PDM5. Factor analysis on the six items further confirms the validity of the items used, while only one factor is extracted, which explains 37.734% of total variance.

A reliability analysis of the items gives the following result:

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Alpha if Item Deleted |
|---|---|---|---|---|
| PDM1 | 13.7633 | 19.7175 | .2805 | .6542 |
| PDM2 | 12.9112 | 18.9861 | .2678 | .6633 |
| PDM3 | 12.6805 | 16.8378 | .5014 | .5782 |
| PDM4 | 13.4793 | 17.6320 | .4325 | .6042 |
| PDM5 | 14.0769 | 18.0000 | .4069 | .6135 |
| PDM6 | 13.3550 | 16.5161 | .4621 | .5913 |
| Alpha = .6612 | | | | |

**Table 7.12: Reliability analysis product modularity**

Only deleting item PDM2 from the scale never leads to a small increase in the Cronbach alpha. The increase is so small however, that it is decided to include all items in the scale. The top 10 and bottom 10 of most (least) modular products looks as follows:

| | | | |
|---|---|---|---|
| **1** | Travel | **160** | Handmade conducting batons |
| **2** | Kilts | **161** | Silverware |
| **3** | Fine art | **162** | Wool sweaters with traditional Norwegian patterning |
| **4** | Custom made fiberglass canoes & accessories | **163** | Furniture, custom high-end |
| **5** | Shoes & boots made to order | **164** | Ceramic Platters with a home painted on it |
| **6** | Horse Harness | **165** | Handbags |
| **7** | Hand painted wall coverings | **166** | Body boards |
| **8** | True Custom steering wheels | **167** | Refrigerator magnets |
| **9** | Gift baskets | **168** | Sculpture |
| **10** | Roller-skates | **169** | Recycled lumber |

**Table 7.13: Product modularity ranking**

Although the reliability of the scale was sufficiently, we immediately see the fairly low intuitive validity of the scale. Why are handbags and wool sweaters less modular than, e.g., kilts and canoes? Let's take a look at 5 products (or product types) for which we received the most responses: belts (4), custom homes (6), ceramic tiles (4), furniture (6) and golf clubs (4):

| Product | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|
| **Belts** | 2.5833 | 0.6455 | 1.67 | 3.17 |
| **Custom homes** | 3.1111 | 0.4554 | 2.50 | 3.83 |
| **Ceramic tiles** | 2.1667 | 0.4082 | 1.83 | 2.67 |
| **Furniture** | 2.6111 | 0.7722 | 1.83 | 3.83 |
| **Golf clubs** | 2.8333 | 0.7817 | 2.00 | 3.83 |

**Table 7.14: Product modularity per generic product type**

It can be seen that - with more observations per product - the differences in degree of modularity become more sound and intuitively correct. A home is more modular than, for instance, a ceramic tile. This immediately indicates one important drawback of our study. Despite the satisfactory overall response rate of approximately 10 percent, the number of observations per product or product type remains quite low. Therefore, high variations in - the still somewhat subjective - measurement of product modularity do occur per product (type) and it will be difficult to draw conclusions which will be valid for all types of products (and services). Nevertheless, the introduced measurement for product modularity could well serve as a good starting point for more research, as the reliability of the scale (Cronbach alpha=0.66) is satisfactory high. Obviously, we will keep on using the scale.

## 7.4.5 Process modularity

For the process modularity variable we also wanted to translate the modularity features into specific survey questions. For this purpose, we used the operationalization used by Fine (1998) to distinguish between the place and time of processes (questions B and F). Furthermore, we needed to know what part of the production had been outsourced to other parties (question A). Degree of specialization within production units (i.e. the process modules) was another item, originating from the housing industry (question C), just as the degree of dependency of these units (question E). The distinction between production and assembly (question D) came from the work of Van Hoek & Weken (1998), and it specifically refers to the distinctiveness of the components. The following items were defined.

Using the rating scale shown below, please choose an answer for each set of factors listed. Choose the number which best reflects your opinion of where your manufacturing processes fall on the scale.

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| A | We take care of all product manufacturing ourselves | o | o | o | o | o | Other parties take care of all product manufacturing |
| B | Production units are located in one area | o | o | o | o | o | Production units are geographically dispersed |
| C | Low degree of specialization within production units | o | o | o | o | o | High degree of specialization within production units |
| D | Production and assembly are combined | o | o | o | o | o | Production and assembly are separated |
| E | Large dependency between production units | o | o | o | o | o | Large autonomy for production units |
| F | Continuous production | o | o | o | o | o | Step-wise production |

The Spearman correlations between the six items, coded PCM1 to PCM6 are given below:

| | PCM1 | PCM2 | PCM3 | PCM4 | PCM5 | PCM6 |
|---|---|---|---|---|---|---|
| **PCM1** | 1.000 | .539** | -.062 | .249** | .210** | .011 |
| **PCM2** | .539** | 1.000 | .054 | .413** | .324** | -.087 |
| **PCM3** | -.062 | .054 | 1.000 | .099 | -.020 | .134 |
| **PCM4** | .249** | .413** | .099 | 1.000 | .218** | .022 |
| **PCM5** | .210** | .324** | -.020 | .218** | 1.000 | .100 |
| **PCM6** | .011 | -.087 | .134 | .022 | .100 | 1.000 |

** Correlation is significant at the .01 level (2-tailed)
* Correlation is significant at the .05 level (2-tailed)

**Table 7.15: Inter-item correlations**

Compared to the product modularity scale it immediately becomes clear that the items show less correlation than for product modularity. This already indicates that most likely not all items are valid for measuring process modularity. Factor analysis is used to further analyze this.

**Rotated Component Matrix**[a]

| | Component | |
|---|---|---|
| | 1 | 2 |
| PCM2 | ,839 | |
| PCM1 | ,756 | -,191 |
| PCM4 | ,570 | ,334 |
| PCM5 | ,556 | |
| PCM3 | | ,787 |
| PCM6 | | ,608 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

**Table 7.16: Process Modularity Factor Analysis Rotated Component Matrix**

Using principal component analysis, two components are extracted, which together explain for 50,964% of total variance. In table 7.16 we see that PCM3 and PCM6 together form one component where the other items make up the other. If we observe the items themselves to get better understanding of this, we see that PCM1, PCM2, PCM4 and PCM5 more or less deal with the physical location of the business processes; either in-house at one area, or externally, dispersed over multiple locations. The other component, consisting of PCM3 and PCM6, deals more with the nature of the process, i.e. the degree of specialization and the dispersion over time. Although the second component is not very convincing and solid (the correlation between the two items is not even significant), together they nicely confirm Fine's (1998) operationalization of process modularity into a place and a time dimension. We will therefore use the same distinction within the rest of the analysis.

A reliability analysis of the first (process modularity in space) component leads to the following result, which is satisfactory.

| Item-total Statistics | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Alpha if Item Deleted |
|---|---|---|---|---|
| PCM1 | 6.6747 | 10.5360 | .4167 | .5479 |
| PCM2 | 6.8795 | 9.0278 | .5836 | .4179 |
| PCM4 | 6.5482 | 10.4674 | .3394 | .6056 |
| PCM5 | 6.2651 | 11.1051 | .3018 | .6283 |
| Alpha = .6252 | | | | |

**Table 7.17: Reliability analysis process modularity 'in time'**

A reliability analysis of the second two-item component is not very satisfactory (see table 7.18), as was to be expected and it is therefore decided to remove it for the remainder of the analysis.

| Item-total Statistics | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Alpha if Item Deleted |
|---|---|---|---|---|
| PCM3 | 3.5412 | 2.1669 | .0894 | . |
| PCM6 | 3.6059 | 1.6130 | .0894 | . |
| Alpha = .1626 | | | | |

**Table 7.18: Reliability analysis process modularity 'in place'**

### 7.4.6 Supply Chain modularity

The final modularity variable is supply chain modularity. Once again, we wanted to translate the generic modularity features into specific questions. The first question already somewhat diverges from these features, but we felt it was necessary to include the question. It originates from the work of Jarvenpaa & Ives (1994) who introduce the thinking-in-reverse philosophy. We already discussed this philosophy in the chapters 3 and 4 where we validated Modular Network Design and discussed the background of the approach. This question tries to bridge earlier work on MND and the currently described research on business modularity. Because this question differs from the modularity features, we do not expect this item to fit perfectly in the supply chain modularity operationalization. We expect however, that there may be some relationship between this item and the other variables of our framework.

The other questions (items) do refer to the supply chain modularity features. The second question refers to the loose coupling of the supply chain modules, just as the third question. The third question is directly taken from the work of Fine (1998). Question four refers to the standardization of interfaces (i.e. rules and procedures) between supply chain modules. The fifth question refers to the ease of switching, i.e. the ability to make many different configurations consisting of different supply chain modules. This question also relates to the autonomy of the organization itself and the "surrounding" modules. The final question already tries to establish a linkage between the components of a product and the supply chain components. In other words it refers to the mapping of functions and components of a supply chain.

This led to the formulation of the following items, coded as SCM1 to SCM6:

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| We contact our suppliers mainly for issues relating to specific customer requests | o | o | o | o | o |
| We mostly engage in temporary, short-term contracts with our suppliers | o | o | o | o | o |
| We use multiple, interchangeable suppliers for our key components | o | o | o | o | o |
| We use the same trade rules and procedures for all our suppliers | o | o | o | o | o |
| We are completely free to buy from any supplier that we want | o | o | o | o | o |
| Our product components are very much "off-the-shelf" items which are supplied by many different firms | o | o | o | o | o |

Once again we commence with analyzing the inter-item Spearman correlations. Here we also see not so many significant correlations between the items. A factor analysis may shed more light on this.

| | **SCM1** | **SCM2** | **SCM3** | **SCM4** | **SCM5** | **SCM6** |
|---|---|---|---|---|---|---|
| **SCM1** | 1.000 | .178* | .157* | .160* | .118 | -.025 |
| **SCM2** | .178* | 1.000 | .316** | .143 | .192* | .151* |
| **SCM3** | .157* | .316** | 1.000 | .138 | .348** | .359** |
| **SCM4** | .160* | .143 | .138 | 1.000 | .130 | .137 |
| **SCM5** | .118 | .192* | .348** | .130 | 1.000 | .151* |
| **SCM6** | -.025 | .151* | .359* | .137 | .151* | 1.000 |

** Correlation is significant at the .01 level (2-tailed)
* Correlation is significant at the .05 level (2-tailed)

**Table 7.19: Inter-item correlations**

Just as with the process modularity analysis, two components can be extracted, together explaining for 51.777% of total variance. The first component consists of SCM3, SCM4, SCM5 and SCM6. The second component consists of SCM1 and SCM2, although the latter could just as well be grouped under the first component. It was already expected that SCM1 would fall out of the supply chain modularity scale. This variable will from now be denoted as degree of supply chain reversiveness. It relates to what extent the supply chain is organized based on specific customer requests (high reversiveness) or on common practice, where the customer is the end-point of the chain (low reversiveness).

We repeat the factor analysis with the remaining 5 items. This results in one factor, together explaining for 39.839% of total variance. A reliability analysis of the items in the scale further confirms the validity of the scale consisting of the five items SCM2 to SCM6.

The results are as follows:

Item-total Statistics

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Alpha if Item Deleted |
|---|---|---|---|---|
| SCM2 | 13.7135 | 11.0762 | .3136 | .5829 |
| SCM3 | 13.3918 | 9.8868 | .5197 | .4640 |
| SCM4 | 12.9591 | 12.5807 | .2599 | .6012 |
| SCM5 | 12.2924 | 11.7493 | .4087 | .5365 |
| SCM6 | 13.8187 | 10.8081 | .3374 | .5700 |

Alpha = .6081

**Table 7.20: Reliability analysis supply chain modularity**

We see that excluding SCM2 from the first component does decrease the Cronbach alpha, so it is decided to keep it included in this component.

### 7.4.7 Concurrency between the three dimensions

Subsequently, we need a formula to indicate the level of concurrency between the three business dimensions product, process and supply chain. An option would be to take the standard deviation of the three variables; a low standard deviation would indicate a high concurrency. However, such a measure does not include the degree of modularity of the three dimensions, which is preferable. Therefore, it is decided to take the following formula, which includes both the mean and the standard deviation:

$$Concurrency = \frac{Mean(ProdMod, ProcMod, SCMod)}{StDev(ProdMod, ProcMod, SCMod)}$$

The distribution of this newly created variable is displayed in the following histogram.

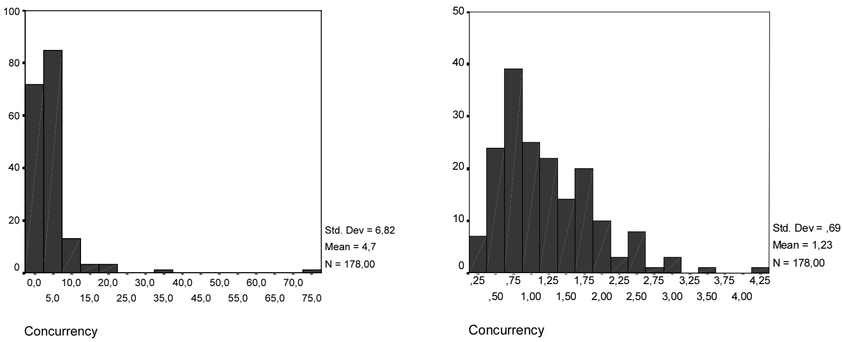



**Figure 7.2a-b: Concurrency between the three dimensions**

We notice that this distribution is very skewed to the right Therefore, we take the natural logarithm of the concurrency variable which enables us to include it a regression analysis. Figure 7.2b shows the distribution of the newly defined variable. We observe that this variable is indeed closer to a normal distribution.

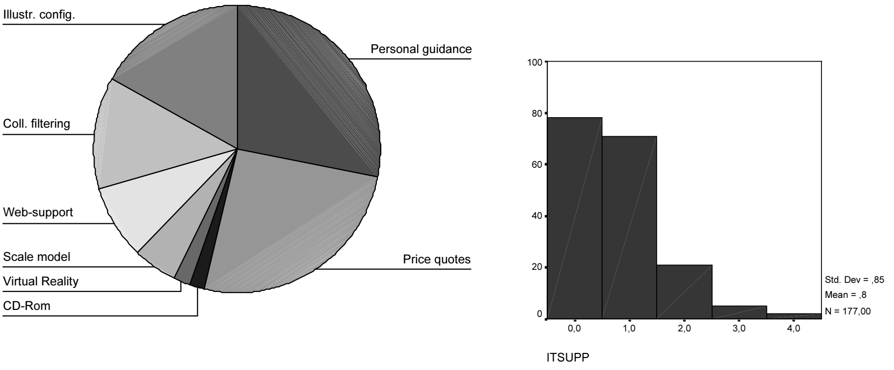
### 7.4.8 Use of ICT

The work of Mendelson & Pillai (1998) helps us in getting a better understanding of different ICT applications and how they could enable mass-customization and modularity. In their study, they initially defined 10 ICT variables: E-mail, voice mail, mobile phone, pager, videoconferencing, supplier EDI, order processing, confirmation of delivery dates, price quotes and configuration support. After carrying out a business survey and performing a factor analysis on the IT variables, the results showed that four main factors could be distinguished. Factor 1 corresponded to use of sales-support tools (configuration support and prices quotes) on customer sites. Finally, factor 2 corresponded to the use of order-management systems (order processing and confirmation of delivery dates). Factor 3 corresponded to the use of technologies that support human communications (e-mail, voice mail and mobile phone). Factor 4 reflected both structured (EDI) and human (pager, videoconferencing) communications with suppliers. According to Mendelson & Pillai, a further classification could be made by grouping the variables from factor 1 and 2 together and those of factor 3 and 4 as well. This led to two generic IT variables. The first (type I) is the composite of factor 1 and 2, denoted as the use of portable systems and support tools on customer sites. The other (type II) is denoted as team and supplier communications. Type I applications will most likely be used for supporting the customer in customizing the product or improving order-processing in general, where type II ICT will be used for improving process and supply chain performance or increase overall performance. We follow the same distinction.

The use of type I applications was measured with three questions. The first just consisted of 8 binary variables indicating which tools or mechanisms were used to support the customers in the configuration process. CD-Rom, Virtual Reality, web-based support tools and collaborative filtering are were denoted as ICT tools. The others were not. The resulting IT-support variable (ITSUPP) simply was the number of IT-support tools used.

Please indicate how your customers are supported in the process of designing and selecting their product (more than one answer allowed):
o Personal guidance and advice (physical)
o Price quotes
o CD-Rom
o Virtual Reality applications
o Scale model
o Web-based support tools (e.g., electronic shop assistant)
o Collaborative filtering (personal advice based on other people's purchases)
o Standard illustrative configurations

The answers were distributed as follows (figure 7.3a); the distribution of the resulting variable ITSUPP is displayed in figure 7.3b.

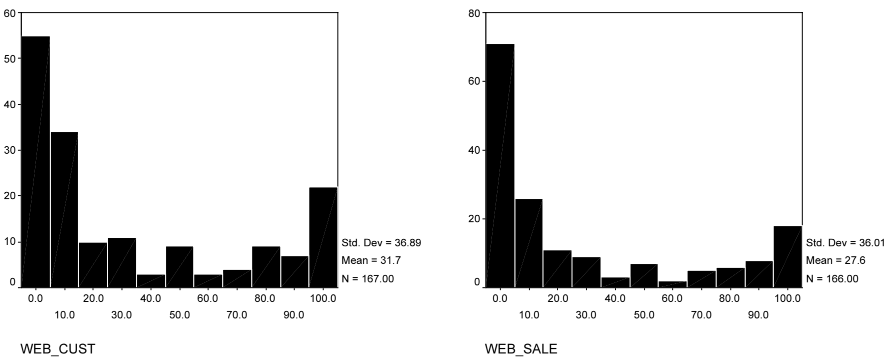



**Figures 7.3a-b: Customer support**

The next type I ICT questions explicitly referred to the use of the World Wide Web for customer communications.

Please indicate the percentage of customers who bought your product on-line (via the World Wide Web) and the percentage of total sales that were completed on-line in the past 12 months:
[    ] percent on-line customers and [    ] percent on-line sales

The answers were distributed as follows.




**Figures 7.4a-b: Use of world wide web**

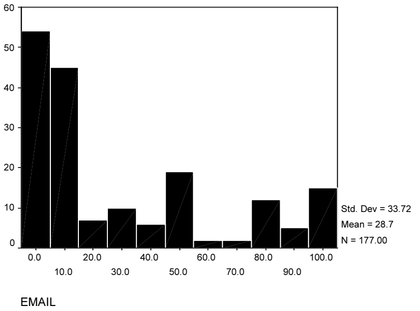
The next number of question referred to type II ICT applications for team and supplier communications. Massetti & Zmud (1996) identify four distinct facets of EDI measurement: volume (fraction of transactions done through EDI), diversity (number of different types of documents handled by EDI), breadth (fraction of suppliers with EDI connections) and depth (the degree to which the firm's computer system is coupled with suppliers' systems). Just as Mendelson & Pillai (1998) we only use the breadth dimension, mainly because we did not want our survey to become too long. Measuring the other variables would have required the respondents to carry out an investigation for themselves to arrive at reasonable measurements as well.

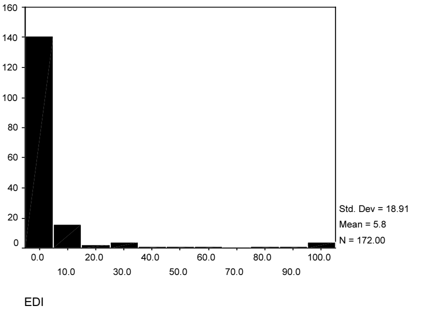
> Please indicate the percentage of suppliers with whom you have an Electronic Data Interchange (EDI) connection:
> ☐ percent

The same reasoning was followed to measure the breadth of E-mail usage.

> Please indicate the percentage of suppliers with whom you communicate via E-mail:
> ☐ percent

The distribution of answers was as follows.




**Figures 7.5a-b: Use of EDI and E-mail**

Finally, we used the instrument defined by Grover (1993) to measure the role of IT in an organization. We adapted it slightly to measure the role of IT in the customization strategy specifically.

> Which one of the following best describes the role of Information Technology (IT) in your organization? Please check only one:
> 1 o Traditional Role: IT supports operations and facilitates decision support and administrative functions, but is not related to our customization strategy.
> 2 o Evolving Role: IT supports the customization strategy. Information System (IS) groups actively support the organization's strategies but are not an integral part of the strategy formulation process.
> 3 o Integral Role: IT is integral to the customization strategy. Highly proactive orientation to IT, where IS and executive management work together to change competitive patterns in the industry.

From the digiCHOICE database we already knew which organizations allow their customers to create the products on-line. This is our final IT-variable for which the answers were distributed as follows:

| Role of IT | | | Create Online? | | |
|---|---|---|---|---|---|
| **Value** | **Freq.** | **Perc.** | **Value** | **Freq.** | **Perc.** |
| **1** | 77 | 41.6 | **0** | 156 | 84.3 |
| **2** | 54 | 29.2 | **1** | 20 | 10.8 |
| **3** | 33 | 17.8 | | | |
| **Missing** | 21 | 11.4 | **Missing** | 9 | 4.9 |
| **Total** | 185 | 100 | **Total** | 185 | 100 |

**Table 7.21: Role of ICT and possibility to create online**

As the first step we will analyze the (Spearman) correlations between all IT-related variables:

| | **Create Online** | **EDI** | **E-mail** | **IT Role** | **IT support** | **Web cust'rs** | **Web sales** |
|---|---|---|---|---|---|---|---|
| **Create Online** | 1.000 | .148 | .045 | .255** | .092 | .285** | .313** |
| **EDI** | .148 | 1.000 | .199** | .071 | .015 | .142 | .126 |
| **E-mail** | .045 | .199** | 1.000 | .268** | .207** | .386** | .269** |
| **IT Role** | .255** | .071 | .268** | 1.000 | .274** | .339** | .314** |
| **IT support** | .092 | .015 | .207** | .274** | 1.000 | .155* | .157* |
| **Web cust'rs** | .285** | .142 | .386** | .339** | .155* | 1.000 | .799** |
| **Web sales** | .313** | .126 | .269** | .314** | .157* | .799** | 1.000 |

** Correlation is significant at the .01 level (2-tailed)

* Correlation is significant at the .05 level (2-tailed)

**Table 7.22: Correlations between ICT variables**

Approximately half of the bivariate correlations are significant. A factor analysis may show a further categorization of the variables. Three factors are found, which together explain for 66.471% of total variance:

**Total Variance Explained**

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2.454 | 35.058 | 35.058 | 2.454 | 35.058 | 35.058 | 2.136 | 30.509 | 30.509 |
| 2 | 1.182 | 16.879 | 51.937 | 1.182 | 16.879 | 51.937 | 1.401 | 20.011 | 50.520 |
| 3 | 1.017 | 14.534 | 66.471 | 1.017 | 14.534 | 66.471 | 1.117 | 15.951 | 66.471 |
| 4 | .897 | 12.808 | 79.279 | | | | | | |
| 5 | .650 | 9.281 | 88.560 | | | | | | |
| 6 | .618 | 8.827 | 97.387 | | | | | | |
| 7 | .183 | 2.613 | 100.000 | | | | | | |

Extraction Method: Principal Component Analysis.

**Table 7.23: Factor analysis ICT variables**

The rotated component matrix shows the following components with their accompanying variables:

**Rotated Component Matrix**[a]

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| WEB_SALE | .886 | .112 | .124 |
| WEB_CUST | .867 | .119 | .201 |
| create online? | .607 | | -.248 |
| ITSUPP | | .870 | |
| IT_ROLE | .413 | .577 | |
| EMAIL | .227 | .530 | .485 |
| EDI | | | .872 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 4 iterations.

**Table 7.24: Factor analysis component matrices**

We can see that web-customers, web-sales and the possibility to create on-line together make up one component. This is a result we may have expected beforehand. The second component is formed by IT-support and the role of IT within the organization and customization strategy; another expected result. Finally, the third component consists of EDI communications with suppliers. E-mail can be categorized under both component 2 and component 3 - the differences in factor scores are not very high. Obviously, the third component seems most appropriate. Together, these three components intuitively make a lot of sense and they closely relate to our model. The scores obtained from the factor analysis, based on the factor score coefficient matrix (using regression analysis[30]), were saved and will, from now on, be named as follows:

1. Use of the Web (USEOFWEB)
2. IT and customization support (ITCUSSUP)
3. IT and supplier communications (ITCOMM)

### 7.4.9 Clockspeed

Fine (1998) states that 'although intuitively appealing and strategically valuable at a conceptual level, the *measurement* of clockspeed is fraught with complexity at all levels, from the technology, to the firm, and ultimately to the entire industry.' Mendelson and Pillai (1998) elaborate in more detail on the operationalization of clockspeed in the Information Technology industry. Their measurement is based on three drivers: (1) the rate of decline in the prices of input materials; (2) the duration of the product life cycle; and (3) the "freshness" of the product line. Their aggregate clockspeed measure was based on these three variables. It turned out that a simple average of the three would yield a satisfactory composite. Using this measure they found that the computer segments have the highest clockspeeds, followed by consumer electronics, while the specialized industrial electronics segments are the slowest. We will use their measure in our survey.

Could you please give an estimate of the life-cycle of your product:
☐ years

What percentage of your company's 1999's total revenue came from new product introductions?
☐ percent of last year's revenues came from "new" products

Did the prices of input materials increase or decrease over the past five years?
o The prices of input materials increased
o The prices of input materials remained the same
o The prices of input materials decreased

By what percentage on average?
☐ percent per year

Life-cycle unfortunately proved to be somewhat vaguely and ambiguously formulated in the survey, causing a high variance and decreased reliability in the answers, which varied

[30] This results in a number of standardized variables with mean zero and standard deviation 1.

from ".01 years" to "5000 years". Therefore, we decided to rescale the answers into five different categories:

5. Very short life-cycle: answers between 0 and 2 years
4. Short life-cycle: answers between 2 and 5 years
3. Normal life-cycle: answers between 5 and 20 years
2. Long life-cycle: answers between 20 and 50 years
1. Very long life-cycle: answers over 50 years

This led to the following distribution, graphically displayed in figures 7.6a to 7.6c:

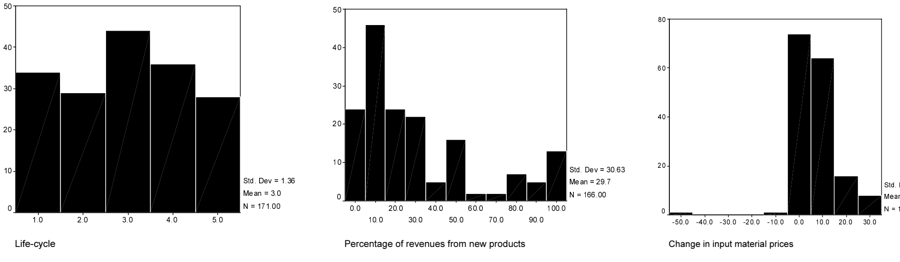



**Figure 7.6a-c: Clockspeed variables**

The second variable, product freshness, proved to be less problematic. The answers varied from 0 to 100 percent, distributed as shown in figure 7.5b. It was decided to use the standardized values of the answers, to make them more or less compatible with the life-cycle scale.

The third category, change in prices of input materials was also straightforward. Surprisingly, only a few of the respondents answered that their input material prices had decreased over the past five years. The large majority reported an increase. Figure 7.5c shows the distribution of answers. Once again, the standardized values were used, only this time the negative value (i.e. outcomes multiplied by -1) of the outcomes was used, while a large increase in prices of input materials indicates a low clockspeed (Mendelson & Pillai 1998). In this manner all three variables had the characteristic that a high value indicated a high clockspeed.

The next step was to analyze whether and how we could transform these three items into one single clockspeed variable. Mendelson & Pillai (1998) used factor analysis and found that a simple average of the three items led to a satisfactory outcome. We will follow the same procedure, starting with the (Spearman) correlation matrix.

| | **Life Cycle** | **Z(Freshness)** | **-Z(input prices)** |
|---|---|---|---|
| **Life Cycle** | 1.000 | .139 | .224** |
| **Z(Freshness)** | .139 | 1.000 | .059 |
| **-Z(Input prices)** | .224** | .059 | 1.000 |

** Correlation is significant at the .01 level (2-tailed)
* Correlation is significant at the .05 level (2-tailed)

**Table 7.25: Clockspeed inter-item correlations**

It can be seen that all three correlations are very low, where only the correlation between Life-cycle and the input material prices is significant at the 0.01 level (2-tailed). All three items are to a large extent independent of each other. The factor analysis (using principal component analysis as extraction method) led to one single component, explaining for 42.114% of total variance. The component matrix looked as follows:

| Component matrix | |
|---|---|
| Life-cycle | 0.742 |
| Z(Freshness) | 0.540 |
| -Z(prices input materials) | 0.648 |

**Table 7.26: Clockspeed factor analysis component matrix**

A new variable was created for the single factor in the final solution (using regression for calculating the factor scores), which we will from now on, denote as Clockspeed. The following figure displays the distribution of the clockspeed measurements over the different product categories as defined by ourselves in section 7.4.1. One can see that the standard deviations of the clockspeed measurements are often higher than the means themselves, therefore, one should not take these measurements too absolute. Still, the Medical, Food and Gift Basket category all score quite high. Intuitively, this seems logical, while these three industries are characterized by short life cycles and especially in the medical industry prices of input materials decreased over the last couple of years. The categories Tiles, Construction and Toys on the other have very low clockspeeds. Among other things, this confirms our findings in the building industry, described in the previous chapter.

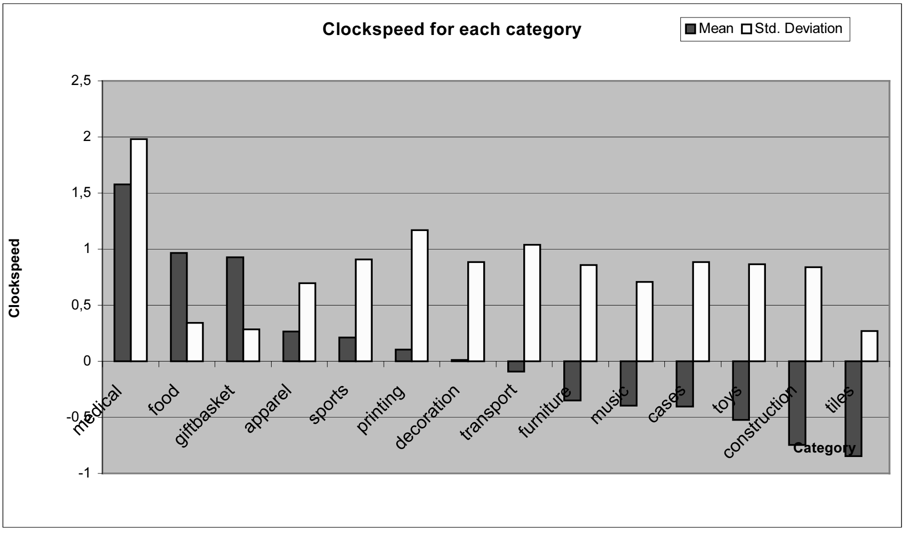



**Figure 7.7: Clockspeed per product category**

When we compare our results with Mendelson & Pillai (1998), two remarkable facts are found. First, as mentioned, the majority of the respondents indicated a rise in the prices of input materials over the past five years. Mendelson & Pillai investigated the electronics industry and on the contrary, found that most respondents had to deal with decreasing input prices. Probably, this is a particular feature of the electronics industry which does not occur in most other industries. Second, Mendelson & Pillai found a strong correlation between the three items, where we only find a very low degree of correlation. This could mean that the items are really electronics-industry specific clockspeed items and that a more generic operationalization is required, applicable to other industries as well. Nevertheless, we keep on using the current operationalization in the remainder of the analysis, while obviously we do not have any alternatives available.

### 7.4.10 Effectiveness and Performance

Already during the literature analysis and our case study in the housing industry we found that the effectiveness of a (mass-customization) strategy was hard to operationalize and measure. Often, very generic variables and items are used, dedicated for the industry being investigated. For our purposes we needed a very generic measure however.

We used two different, but complementary, approaches to measure the performance of the customizing organizations. The first is a variable that measures the degree of customer freedom, or customization, offered by the companies. The degree of customization has been divided into two items: degree of freedom and number of product configurations a customer can choose from. Both items are measured from the perspective of the organization itself, i.e. as the company itself views it.

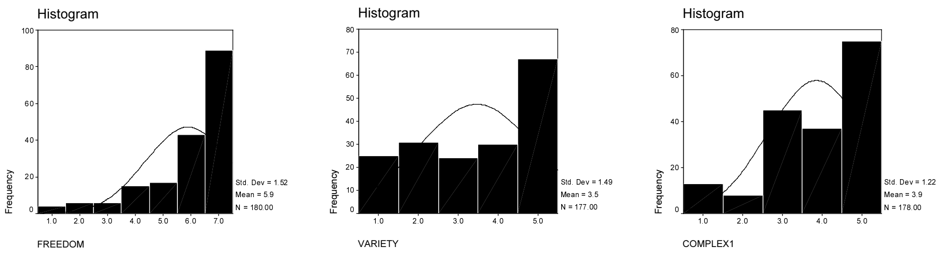
Please indicate the degree of freedom your customer has in customizing your product on the scale below:
No freedom o o o o o o o Full freedom

How many different product configurations can your customer(s) choose from?
o 0-9 o 10-49 o 50-99 o 100-999 o 1000+

Based on the analysis of the product complexity variable (see section 7.4.2), it was decided to add one item from the product complexity scale to degree of customization, i.e. COMPLEX1:

Standardized product o o o o o Differentiated product

The answers were distributed as follows:




**Figures 7.8a-c: Degree of customization**

| | **Complex1** | **Freedom** | **Variety** |
|---|---|---|---|
| **Complex1** | 1.000 | .316** | .203** |
| **Freedom** | .316** | 1.000 | .322** |
| **Variety** | .203** | .322** | 1.000 |

** Correlation is significant at the .01 level (2-tailed)
* Correlation is significant at the .05 level (2-tailed)

**Table 7.27: Inter-item correlations**

We see that all three variables have quite similar distributions; they are significantly correlated as well. Only, the more subjective the item is, the more skewed it is to the left. Seemingly, respondents are more 'optimistic' (i.e. give higher answers) about the degree of customization they offer their customers than the 'facts' indicate. A reliability analysis of the scale gives the following results:

```
Statistics for       Mean   Variance    Std Dev  Variables
      Scale       13.3315     9.4545     3.0748          3

Item-total Statistics

               Scale          Scale      Corrected
               Mean          Variance      Item-         Squared          Alpha
              if Item        if Item       Total        Multiple         if Item
              Deleted        Deleted    Correlation    Correlation       Deleted

COMPLEX1       9.4270         6.1896        .2957          .0955           .5516
FREEDOM        7.4101         4.3563        .4423          .1966           .3195
VARIETY        9.8258         4.8678        .3685          .1523           .4488

Alpha =   .5546           Standardized item alpha =   .5511
```

**Table 7.28: Reliability analysis degree of customization**

This means that a scale based on the average of the three items is sufficiently reliable.

Furthermore, we wanted to find out how important it was for the organizations to actually offer customized products to their customers. Is customization the main strategic objective for the organization, or are other objectives like efficiency or innovation more important? As a result, we may find exactly which companies combine a customization strategy with an efficiency strategy and thus are really trying to mass-customize their offerings. To analyze this aspect of firm performance, we fall back on the work of Ulrich & Ellison (1999) and Treacy & Wiersema (1992). We used the former to come up with the question structure and the latter for question content.

Ulrich & Ellison (1999) developed an instrument to measure *Holistic* as a variable in their study on holistic customer requirements and the design-select decision. Holistic is an index of the degree to which the customer requirements for the product are holistic. They asked the respondents first to construct a list of five to ten "attributes" that customers consider when selecting and purchasing the product. Then they asked them to allocate 100 percent points to indicate the relative importance of these attributes. For each attribute, the respondent was then instructed to assess "the approximate number of components that contribute substantially to determining the performance of the product with respect to the attribute." Finally, for each attribute, the respondent was asked to indicate how difficult it is to predict the performance of the product with respect to the attribute.

We have used the same questions structure as Ulrich & Ellison did, but we obviously focused on another issue: performance of the organization. We used the work of Treacy & Wiersema for this purpose. They define three, what they call, value disciplines – operational excellence, customer intimacy and product leadership. They argue that companies that have taken leadership positions in their industries in the last decade typically have done so by narrowing their business focus to one of these disciplines. Operational excellence refers to providing customer with reliable products or services at competitive prices and delivered with minimal difficulty or inconvenience. Customer intimacy means segmenting and targeting markets precisely and then tailoring offerings to match exactly the demands of those niches. Product leadership means offering customers leading-edge products and services that consistently enhance the customer's use or application of the product, thereby making rivals' goods obsolete.

We used these three disciplines for the first part of our questions, by defining six business objectives, two from each discipline. Objectives 1 and 4 refer to operational excellence, 2 and 5 to customer intimacy and 3 and 6 to product leadership. We also left two options free to choose by the respondents. The next part of the question was to allocate 100 percent points among the chosen objectives and in the final part respondents were asked to indicate to what extent they already had achieved these objectives (from 0 to 100%).

Below you find six pre-defined business objectives related to the (mass-)customization of products. Could you indicate which of these objectives you wanted to achieve when you decided to offer customizable products to your customers? You may also formulate additional business objectives and select them.

o 1 Cost minimization
o 2 Increased customer intimacy
o 3 High product innovation rate
o 4 Competitive product pricing
o 5 Increase product variety
o 6 Minimize product development time
o 7 __________
o 8 __________

Can you allocate 100 percent points to the objectives you selected according to their relative importance?

| | |
|---|---|
| 1 Cost minimization | …. points |
| 2 Increased customer intimacy | …. Points |
| 3 High product innovation rate | …. Points |
| 4 Competitive product pricing | …. points |
| 5 Increase product variety | …. points |
| 6 Minimize product development time | …. points |
| o 7 | …. points |
| o 8 | …. points |

Finally, can you please indicate for the above objectives to what extent you have achieved them?

| | | | | | |
|---|---|---|---|---|---|
| 1 Cost minimization | o 0% | o 25% | o 50% | o 75% | o 100% |
| 2 Increased customer intimacy | o 0% | o 25% | o 50% | o 75% | o 100% |
| 3 High product innovation rate | o 0% | o 25% | o 50% | o 75% | o 100% |
| 4 Competitive product pricing | o 0% | o 25% | o 50% | o 75% | o 100% |
| 5 Increase product variety | o 0% | o 25% | o 50% | o 75% | o 100% |
| 6 Minimize product development time | o 0% | o 25% | o 50% | o 75% | o 100% |
| 7 | o 0% | o 25% | o 50% | o 75% | o 100% |
| 8 | o 0% | o 25% | o 50% | o 75% | o 100% |

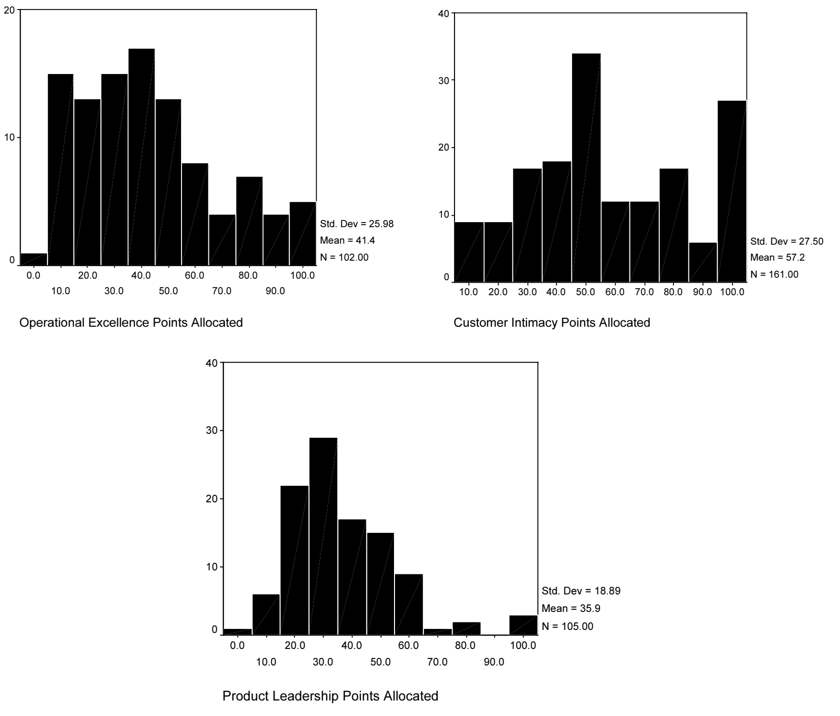
First, all answers given in the open category – a total of 59 - had to be recoded into one of the three main categories: operational excellence, customer intimacy and product leadership. After this had been done, the following distribution for each of the objectives was found. The numbers 0 to 4 indicate the number of times a respondent has selected an objective belonging to a certain category.

| **Operational Excellence** | | | **Customer Intimacy** | | | **Product Leadership** | | |
|---|---|---|---|---|---|---|---|---|
| **Value** | **Freq.** | **Perc.** | **Value** | **Freq.** | **Perc.** | **Value** | **Freq.** | **Perc.** |
| **0** | 77 | 41.6 | **0** | 17 | 9.2 | **0** | 72 | 38.9 |
| **1** | 50 | 27.0 | **1** | 55 | 29.7 | **1** | 71 | 20.0 |
| **2** | 53 | 28.6 | **2** | 100 | 54.1 | **2** | 37 | 20.0 |
| **3** | 3 | 1.6 | **3** | 10 | 5.4 | **3** | 3 | 1.6 |
| **4** | 0 | 0 | **4** | 1 | .5 | **4** | 0 | 0 |
| **Missing** | 2 | 1.1 | **Missing** | 2 | 1.1 | **Missing** | 2 | 1.1 |
| **Total** | 185 | 100 | **Total** | 185 | 100 | **Total** | 185 | 100 |

**Tables 7.29: Organizational objectives**

Summarizing, we see that Operational Excellence objectives were selected 165 times (50x1 + 53x2 + 3x3), Customer Intimacy 289 times and Product Leadership 154 times. This clearly indicates the strong preference for strategies focusing on customer intimacy, which is obviously not a surprise.

Next, we can further classify these categorizations based on the priority points each of the respondents allocated to each of the selected objectives. The distributions of the points allocated for each of the objectives are visualized in the figures below.




**Figures 7.9a-c: Points allocated per objective**

Once again, we see a strong preference for customer intimacy as strategic objective. The third question asked about the objectives was to what extent the respondent already had achieved each of the selected objectives. These percentages are combined with the priority points allocated to each of the objectives. In this manner we arrive at a three-dimensional performance measure for each of the respondents. An example may illustrate this. Suppose one respondent selected four objectives: one operational excellence, two customer intimacy and one product leadership. The following table depicts the points allocated and the percentage of achievement. The last column represents the total performance of the respondent on each dimension[31].

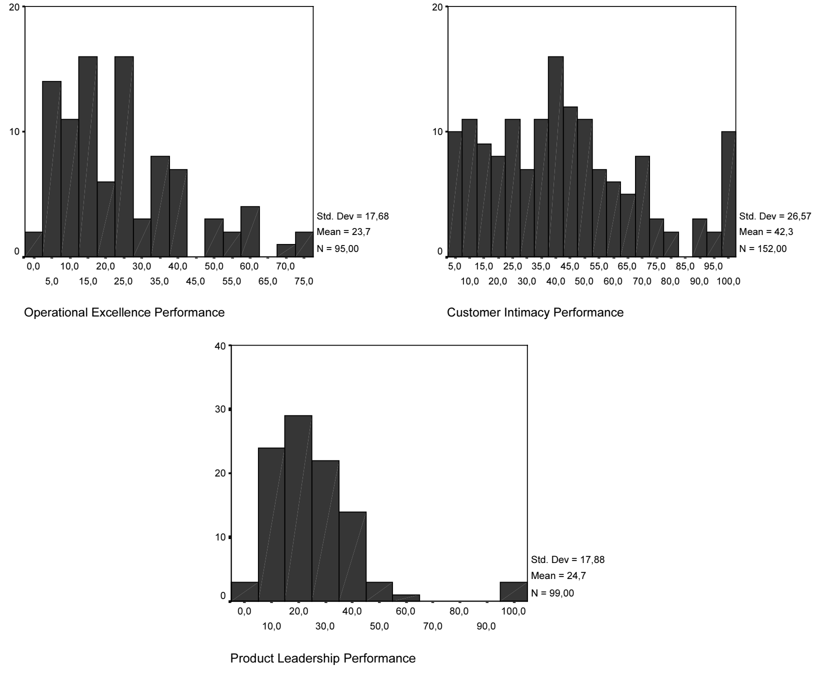
| Selected objective | Points allocated | Percentage Achieved | Total performance |
|---|---|---|---|
| **Operational Excellence** | 30 | 75% | 22.50 |
| **Customer Intimacy I** | 20 | 100% | 50 (1x20 + 0.75x40)[32] |
| **Customer Intimacy II** | 40 | 75% | |
| **Product Leadership** | 10 | 50% | 5 |

**Table 7.30: Example of total performance calculation**

[31] In case a respondent allocated zero points to a certain objective category, the resulting performance score is an empty cell, which will thus not be included in the remaining calculations.

[32] This is thus the overall score on customer intimacy, as a combination of two selected objectives in this category.

The distributions of the performance dimensions are shown in the histograms below.




**Figures 7.10a-c: Performance scores per objective**

We observe that, although operational excellence on average is given higher priority, product leadership scores better on the performance scale – on average. Customer intimacy stays on top.

## 7.4.11 Conclusions about instrumentation and reliability

Finally, to conclude section 7.4 about instrumentation and reliability we will summarize our findings. The following table displays the Cronbach alpha's for the different scales used to measure the variables of our framework:

| Variable | Number of items | Cronbach alpha |
|---|---|---|
| **Product complexity** | 5 | 0.7062 |
| **Product modularity** | 6 | 0.6612 |
| **Process modularity – in place** | 4 | 0.6252 |
| **Process modularity – in time** | 2 | 0.1626 |
| **Supply chain modularity** | 5 | 0.6081 |
| **Use of WWW** | 3 | n.a. |
| **IT for customer support** | 2 | n.a. |
| **IT for team & supplier communications** | 2 | n.a. |
| **Clockspeed** | 3 | n.a. |
| **Degree of Customization** | 3 | 0.5546 |

**Table 7.31: Overview of variable reliability**

With the exception of process modularity in time, all variables demonstrate sufficient reliability in their measurement. Especially the Cronbach alpha's for the three modularity measurements are satisfactory and may thus be used in future researches on business modularity.

The measurement of the three IT variables just as the clockspeed measure were all scores obtained from the factor analysis, based on the factor score coefficient matrix (using regression analysis). The result of such an analysis is a number of standardized variables with mean zero and standard deviation one. In the case of the clockspeed variable two remarkable facts were found, at least when compared with the results of Mendelson & Pillai (1998). First, the majority of the respondents indicated a rise in the prices of input materials over the past five years (Mendelson & Pillai investigated found that most respondents in the electronics industry had to deal with decreasing input prices). Second, Mendelson & Pillai found a strong correlation between the three items, where we only find a very low degree of correlation. This could mean that the items are really electronics-industry specific clockspeed items and that a more generic operationalization is required, applicable to other industries as well.

Finally, we used a special method to determine the effectiveness or performance of the organization under investigation. First, we determined the degree of customization (or freedom) of the product. Second, we used a three-step approach to analyze the importance of a customization strategy for the organization and its subsequent achievement in this respect. The latter method may have led to somewhat subjective measurements of performance, for instance, because respondents were asked to indicate to what extent they had reached their previously formulated objectives, with answers varying from 0 to 100 percent. Obviously while no level zero measurement was done and no time frame was included this may have limited the compatibility of the answers a little bit. Still, the method offers plenty of insight in the firms strategic choices and its achievements.

## *7.5 Model Validation*

### 7.5.1 Introduction

The following step is to validate our research model, i.e. the hypotheses concerning the relationships between the variables. We will analyze our research framework on a step-by-step basis, starting with an analysis on product modularity and its dependent variables, followed by an investigation into the three dimensions of modularity and their mutual relationships. Finally, we arrive at an analysis of the performance of the organization in relation to the concurrency of the three modularity dimensions and other variables, like clockspeed and use of ICT.

### 7.5.2 Product Modularity

As the first step we will analyze the variables that influence the degree of product modularity. Based on our research framework, we defined the following independent variables:

- Heterogeneity of demand
- Customer Involvement (i.e. willingness and ability)

We use the Ordinary Least Squares (regression) procedure to determine the values of each of the parameters. The results are shown below.

| | | Unstandardized Coefficients | | Standardized Coefficients | | |
|---|---|---|---|---|---|---|
| **Model** | | **B** | **Std. Error** | **Beta** | **t** | **Sig.** |
| | **Intercept** | 2.097 | .409 | | 5.132 | .000 |
| | **Heter. Demand** | 6.994e-02 | .096 | .067 | .732 | .465 |
| | **Customer Sensitivity** | 7.572e-02 | .115 | .060 | .656 | .512 |

**Dependent Variable: Product Modularity**
F-value = 1.061 , sig. = .348, $R^2$ = .013, N = 168.

**Table 7.32: Parameter Estimation**

We do not find satisfactory evidence for a relationship between heterogeneity of demand and customization sensitivity on the one hand and product modularity on the other. None of the independent variables seems to significantly impact the degree of product modularity. The $R^2$ of the model is also rather low. This means that we do not find enough evidence to support proposition P1 of the research framework.

Subsequently, the following four variables function as so-called moderating variables. Baron and Kenny (1986:1174) define a moderator variable as one that "affects the direction or strength of the relation between an independent or predictor variable and a dependent or criterion variable". In particular, we expect the following variables to moderate the relation between Involvement and Product Modularity. The variables are:

- Customer Type (i.e. private persons or businesses).
- Use of the World Wide Web for sales and support
- IT for Customer Design Support
- Product complexity

Testing for moderator effects entails the comparison of two models: Model 1, the baseline model, includes the hypothesized moderating variable only as an independent variable; Model 2 adds the hypothesized interaction effects to Model 1. If the $R^2$ value for Model 2 is significantly greater than the $R^2$ value for Model 1, the hypothesized moderator variable is indeed a moderator (Arnold, 1982).

| Dep.var.: Product Modularity | Model 1 | | Model 2 | |
|---|---|---|---|---|
| **Independent Variables** | **B** | **Sig.** | **B** | **Sig.** |
| **Intercept** | 2.404 | .001 | -.922 | .696 |
| **Heter. Demand** | 1.192e-02 | .916 | .534 | .207 |
| **Customer Sensitivity** | 8.469e-02 | .540 | .443 | .432 |
| **Complex** | 9.246e-02 | .246 | -6.271e-02 | .921 |
| **Customer Type** | -.206 | .251 | 2.825 | .039 |
| **IT Support** | 3.864e-02 | .610 | .384 | .503 |
| **Use of Web** | .160 | .044 | .415 | .569 |
| **Complex * HD** | | | -.104 | .429 |
| **Customer Type * HD** | | | -.248 | .355 |
| **IT support * HD** | | | .113 | .333 |
| **Use of Web * HD** | | | -.115 | .308 |
| **Complex * CS** | | | .145 | .355 |
| **Customer Type * CS** | | | -.563 | .083 |
| **IT Support * CS** | | | -.205 | .142 |
| **Use of Web * CS** | | | 5.364e-02 | .752 |
| | | | | |
| **$R^2$** | .071 | | .149 | |
| **F-value for change in $R^2$** | | | 1.264 | |
| **Df (numerator/denominator)** | 6/117 | | 8/109 | |
| **p-value for change in $R^2$** | | | .270 | |

**Table 7.33: Testing for significance of interaction variables**

We notice that the increase in F-value for the model with interaction terms is not significant (p-value = .270). None of the interaction variables are significant; only customer type seems to be of influence. Therefore, we reduce the model to only one moderator variable: type of customer.

| Dep.var.: Product Modularity | Model 1 | | Model 2 | |
|---|---|---|---|---|
| **Independent Variables** | **B** | **Sig.** | **B** | **Sig.** |
| **Intercept** | 2.723 | .000 | -.331 | .792 |
| **Heter. Demand** | 7.079e-03 | .942 | .365 | .209 |
| **Customer Sensitivity** | 7.120e-02 | .536 | .501 | .145 |
| **Customer Type** | -.285 | .051 | 2.209 | .022 |
| **Customer Type * HD** | | | -.300 | .165 |
| **Customer Type * CS** | | | -.348 | .165 |
| | | | | |
| **$R^2$** | .030 | | .072 | |
| **F-value for change in $R^2$** | | | 3.513 | |
| **Df (numerator/denominator)** | 3/160 | | 2/158 | |
| **p-value for change in $R^2$** | | | .032 | |

**Table 7.34: Alternate model for product modularity**

With the alternate, stripped model we observe that customer type is indeed a significant variable. Even more, there seems to be a direct effect between customer type and product modularity. Companies that mainly serve other companies as their customers make less use of modular design than business-to-consumer organizations. What can be the theoretical explanation behind this effect? Most likely, in a business-to-business environment modularity may often be too limited for the customers. They require cut-to-fit products instead of products built from predetermined building blocks.

### 7.5.3 Modularity in three dimensions

Just as in the *GW*-case study, we expect to find positive relationships between the three business dimensions product, process and supply chain modularity. The individual variable analysis already showed that one the items of the process modularity variable were not all measurements for the same variable; we had to divide the variable into two parts: process modularity in place and time. We will only include process modularity in place in our analysis, while the other variable was not adequately operationalized.

The correlation matrix which shows the Spearman correlations between the three variables is displayed below.

| | Product Modularity | Process Modularity | Supply Chain Modularity |
|---|---|---|---|
| **Product Modularity** | 1.000 | .160* | .257** |
| **Process Modularity** | .160* | 1.000 | .051 |
| **Supply Chain Modularity** | .257** | .051 | 1.000 |

** Correlation is significant at the .01 level (2-tailed)
* Correlation is significant at the .05 level (2-tailed)

**Table 7.35: Correlations between three modularity types**

We observe a relatively low, but significant positive correlation between the variables, except for the relation between process modularity (in place) and supply chain modularity. Let us further explore the relationships between the three variables, this time controlling for a number of other variables that may influence the mutual relationship between the three business modularity variables. These influencing variables are:

- Clockspeed
- IT communications
- Type of customer

Each of these variables is used as a moderating variable on the relationship between the three modularity variables. The outcomes of this analyses are as follows, starting with product and process modularity (where process modularity is considered as the dependent variable in the regression analysis and product modularity the dependent):

| Dep. Var: Process Modularity | Model 1 | | Model 2 | |
|---|---|---|---|---|
| **Independent Variables** | **B** | **Sig.** | **B** | **Sig.** |
| **Intercept** | .839 | .061 | 1.045 | .339 |
| **Product Modularity** | .251 | .032 | .162 | .672 |
| **Clockspeed** | -.130 | .164 | -.358 | .301 |
| **Customer Type** | .549 | .014 | .370 | .657 |
| **IT Supplier Communications** | .141 | .108 | -8.948e-02 | .797 |
| **Clockspeed * PDM** | | | 8.680e-02 | .474 |
| **Customer Type * PDM** | | | 7.578e-02 | .798 |
| **IT Supplier Comm. * PDM** | | | 8.667e-2 | .472 |
| | | | | |
| **R2** | .106 | | .119 | |
| **F-value for change in R2** | | | .522 | |
| **Df (numerator/denominator)** | 4/112 | | 3/109 | |
| **p-value for change in R2** | | | .668 | |

**Table 7.36: Testing for relation between product and process modularity, plus interaction terms**

The regression confirms the positive relationship between product and process modularity (p-level of .032). However, the interaction terms in total do not lead to a significant increase for the model's F-value. Instead, we observe that the supposed moderator variables exert a direct effect on process modularity. All three variables approach significance, varying from .014 to .164.

Next, we will discuss the relation between process and supply chain modularity. The following table depicts the results of the regression analysis with Model 1 and 2, i.e. without and with interaction effects.

| **Dep. Var: Supply Chain Modularity** | **Model 1** | | **Model 2** | |
|---|---|---|---|---|
| **Independent Variables** | **B** | **Sig.** | **B** | **Sig.** |
| **Intercept** | 3.290 | .000 | 3.183 | .000 |
| **Process Modularity** | 1.371e-02 | .832 | 5.420e-02 | .795 |
| **Clockspeed** | 1.056e-02 | .871 | 8.231e-02 | .632 |
| **Customer Type** | 5.532e-2 | .717 | .156 | .707 |
| **IT Supplier Communications** | -7.802e-02 | .212 | -.144 | .418 |
| **Clockspeed * PCM** | | | -2.734e-02 | .664 |
| **Customer Type * PCM** | | | -4.046e-02 | .799 |
| **IT Supplier Comm. * PCM** | | | 2.873e-02 | .689 |
| | | | | |
| **R2** | .015 | | .019 | |
| **F-value for change in R2** | | | .144 | |
| **Df (numerator/denominator)** | 4/116 | | 3/113 | |
| **p-value for change in R2** | | | .933 | |

**Table 7.37: Testing for relation between process and supply chain modularity, plus interaction terms**

This time, we observe that adding moderator variables does not significantly increase the F-value of the model. Not only do the interaction terms not add to the validity of the relationship, the relationship itself between process and supply chain modularity is not confirmed with our data. The correlation matrix already indicated this as well.

Finally, we add the same interaction terms to the relation between product and supply chain modularity.

| **Dep. Var: Supply Chain Modularity** | **Model 1** | | **Model 2** | |
|---|---|---|---|---|
| **Independent Variables** | **B** | **Sig.** | **B** | **Sig.** |
| **Intercept** | 2.589 | .000 | 2.595 | .000 |
| **Product Modularity** | .244 | .002 | .259 | .309 |
| **Clockspeed** | -1.943e-02 | .756 | 7.283e-02 | .750 |
| **Customer Type** | .121 | .416 | .122 | .824 |
| **IT Supplier Communications** | -9.305e-02 | .114 | .370 | .112 |
| **Clockspeed * PDM** | | | -3.954e-02 | .622 |
| **Customer Type * PDM** | | | -1.266e-02 | .949 |
| **IT Supplier Comm. * PDM** | | | -.168 | .037 |
| | | | | |
| **R2** | .100 | | .143 | |
| **F-value for change in R2** | | | 1.801 | |
| **Df (numerator/denominator)** | 4/112 | | 3/109 | |
| **p-value for change in R2** | | | .151 | |

**Table 7.38: Testing for relation between product and supply chain modularity, plus interaction terms**

The relation between product and supply chain modularity is significant. However, adding interaction terms to the equation does not significantly improve the model. Only IT for supplier communications may moderate the relation between the two modularity variables. For this reason we limit the model to only one moderator variable: IT for supplier communications. The results are as follows.

| **Dep. Var: Supply Chain Modularity** | **Model 1** | | **Model 2** | |
|---|---|---|---|---|
| **Independent Variables** | **B** | **Sig.** | **B** | **Sig.** |
| **Intercept** | 2.598 | .000 | 2.615 | .000 |
| **Product Modularity** | .279 | .000 | .273 | .000 |
| **IT Supplier Communications** | -7.935e-02 | .203 | .355 | .128 |
| **IT Supplier Comm. * PDM** | | | -.156 | .054 |
| | | | | |
| **R2** | .105 | | .131 | |
| **F-value for change in R2** | | | 3.780 | |
| **Df (numerator/denominator)** | 2/127 | | 1/126 | |
| **p-value for change in R2** | | | .054 | |

**Table 7.39: Alternate model for supply chain modularity**

Our initial idea that IT for supplier communications may indeed be a significant moderator variable between product and supply chain modularity is confirmed by table 7.39. The negative value for the interaction parameter (-.156) indicates however that the relation between product and supply chain modularity is loosened when organizations make more use of IT for communicating with their suppliers. This is obviously a surprising result. An explanation may be for this phenomenon that the IT applications used by the respondents for communication and information exchange with their suppliers did not loosen their coupling but instead tighten it. One often sees that, for instance, EDI or PDI require very specific investments, numerous agreements on standards and formats and therefore, increase the dependency and binding between the partners (Ekering 2000). These partnerships often have high relation-specificity and switching costs; both features of a low degree of modularity.

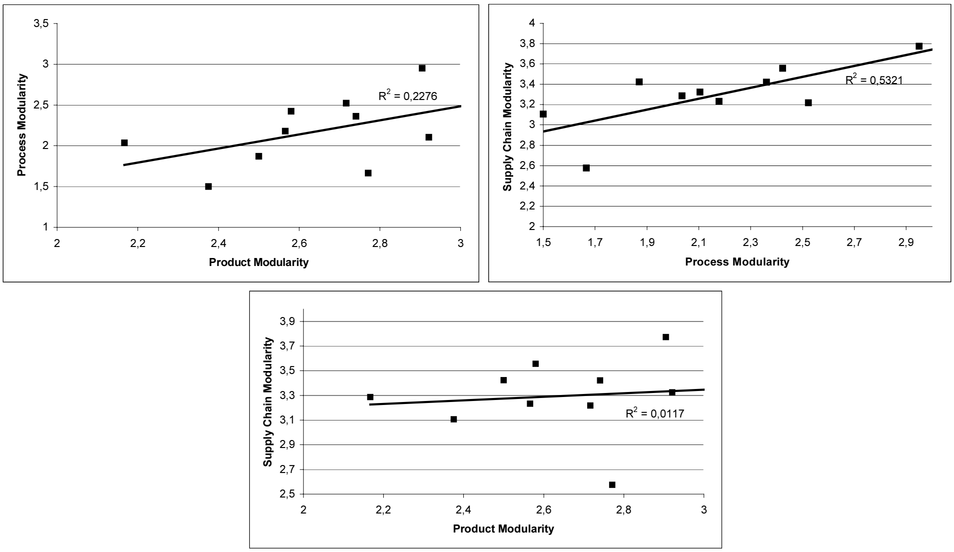
In general we notice that the proposed relationships between the three modularity variables are not very strong. Inter-variable correlations are low and the regression models have low (adjusted) $R^2$s, ranging from 0.01 to approximately 0.14. These are very low values indeed. To explain this phenomenon we will further examine the data and divide them in the earlier formulated product categories (see section 7.4.1). The reason to do this is that the lack of significance may be explained by the fact that the collection of responses is too heterogeneous and diverse. Comparing and aggregating very distinct products with each other may the reason for the somewhat disappointing findings.

We focus on ten different product categories for which we have sufficient responses. Table 7.40 below shows the averages in product, process and supply chain modularity for each product category, together with the standard deviations.

| | Product Modularity | | Process Modularity | | Supply Chain Modularity | |
|---|---|---|---|---|---|---|
| **Category** | **Mean** | **St.Dev.** | **Mean** | **St.Dev.** | **Mean** | **St.Dev.** |
| **apparel** | 2.57 | 0.84 | 2.18 | 0.93 | 3.23 | 0.80 |
| **cases** | 2.74 | 0.53 | 2.36 | 1.10 | 3.42 | 0.78 |
| **construction** | 2.90 | 0.61 | 2.95 | 1.27 | 3.77 | 0.62 |
| **decoration** | 2.58 | 0.99 | 2.42 | 1.22 | 3.56 | 0.73 |
| **furniture** | 2.50 | 0.86 | 1.87 | 0.91 | 3.42 | 0.87 |
| **medical** | 2.77 | 0.52 | 1.67 | 0.56 | 2.58 | 1.09 |
| **music** | 2.38 | 0.81 | 1.50 | 0.60 | 3.11 | 0.63 |
| **printing** | 2.72 | 0.87 | 2.52 | 0.90 | 3.22 | 0.51 |
| **sports** | 2.92 | 0.81 | 2.10 | 1.11 | 3.33 | 0.84 |
| **tiles** | 2.17 | 0.80 | 2.04 | 0.92 | 3.29 | 0.68 |

**Table 7.40: Business modularity values per product category**

When we graphically compare the modularity types for each product category with each other this looks as follows:




**Figures 7.11a-c: Scatter diagram of modularity types per product category**

In above figures, each dot represents an industry or product category; the lines are trend linear lines, estimated by means of OLS, with the value of $R^2$ attached. This time we find better support for our propositions, albeit that the method does not possess the same statistical robustness as linear regression. We observe that some industries (such as construction, printing and sports) combine high product modularity with high process and supply chain modularity, while we also see that in some industries (such as furniture and music) all three dimensions are low. The linear regression lines drawn through the points all have slopes significantly larger than zero, except for the product-supply chain relation. An explanation for the latter may be the absence of the moderating variable (or interaction term) 'ICT for supplier communications'.

What may be the theoretical rationale behind the fact that some industries possess more modular characteristics than others? Why is the construction industry more modular than the music or furniture industry? Obviously, this is not easy to explain. We did not include a specific industry component in our research framework which may help us in this respect. However, using the findings in the building industry, described in the previous chapter, we are not surprised by the high modularity of the construction industry. Especially, when considering that it in our survey concerns organizations which are trying to customize their products. In these circumstances it may be expected that modularity is even more useful.

Furthermore, what is particularly different in the furniture and music industry compared to, for instance, construction and printing? Most likely, this has to do with the size, the versatility and availability of standards of these industries. The latter industries are industries where numerous, small organizations are active, such that organizations can choose from a myriad of possible suppliers and product components, where in addition many of these components and suppliers are standardized or use standard procedures. Furniture and music may be smaller, less diverse and use much more specialized components. Manufacturing processes in these industries may also be less modular, i.e. production takes place at one location, with production and assembly combined. Once again, these are only 'educated-guesses'. By no means can we theoretically (or even empirically) validate these claims. More research focused on comparing industries in this respect and explaining why certain differences exist , needs to be carried out first.

### 7.5.4 Modularity and organizational performance

The third step of our analysis is to verify the relationship between the use of modularity and firm performance. Firm performance was measured in two ways: degree of customization and achievement of three different strategic objectives. In section 7.4.10, we introduced the three value disciplines operational excellence, customer intimacy and product leadership.

First, we take Degree of Customization as the dependent variable and investigate whether the use of modularity is indeed useful to maximize this customization degree. The following variable is used as independent variable:

- Concurrency in three dimensions

The following three variables function as moderating variables on the relationship between concurrency and customization degree:

- Customer Type
- Clockspeed
- IT for supplier communication

The results of this analysis are as follows:

| Dep. Var: Degree of Customization | Model 1 | | Model 2 | |
|---|---|---|---|---|
| **Independent Variables** | **B** | **Sig.** | **B** | **Sig.** |
| **Intercept** | 4.394 | .000 | 4.402 | .000 |
| **Concurrency** | -.133 | .282 | -.146 | .710 |
| **Clockspeed** | -3.184e-03 | .971 | -5.543e-02 | .807 |
| **Customer Type** | .206 | .317 | .193 | .673 |
| **IT Supplier Comm.** | -7.248e-03 | .931 | -.274 | .321 |
| **Clockspeed * Concurrency** | | | 3.592e-02 | .792 |
| **Customer Type * Concurrency** | | | 4.850e-03 | .987 |
| **IT Supplier Comm. * Concurrency** | | | .203 | .303 |
| **R2** | .017 | | .030 | |
| **F-value for change in R2** | | | .511 | |
| **Df (numerator/denominator)** | 4/116 | | 3/113 | |
| **p-value for change in R2** | | | .675 | |

**Table 7.41: Testing for relation between concurrency and degree of customization, plus interaction terms**

Unfortunately, neither Model 1 nor Model 2 prove to be significant. None of the variables are significantly related to the degree of customization of the product. It seems that the endogenous variables we defined in our research framework do not explain for the variance in customization degree. This means that a concurrent design of the three business dimensions is not a requisite for product customization.

Second, we use the outcomes of the three-step approach on the organizational objectives and the extent to which they have been achieved to further validate the relationship between modularity and performance. A linear regression with multiple dependent variables cannot be done because these variables are strongly dependent with each other. That is, the sum of points allocated is always equal to 100. Therefore, we rely on other approaches just as with the analysis of the three types of modularity in section 7.5.3.

Once again, we start with displaying a table with the average scores and standard deviations per product category for the variables under investigation. We distinguish two different performance variables: priority points given to a certain value discipline (strategic objective) and actual performance scores for each discipline (see also section 7.4.10).

| | Concurr. (log) | Customer Intimacy | | Product Leadership | | Operational Excellence | |
|---|---|---|---|---|---|---|---|
| | | **Priority** | **Score** | **Priority** | **Score** | **Priority** | **Score** |
| **apparel** | 1.24 | 54.94 | 41.92 | 24.03 | 14.02 | 21.03 | 13.03 |
| **cases** | 1.23 | 43.11 | 35.28 | 21.78 | 11.78 | 35.11 | 18.19 |
| **construction** | 1.68 | 43.13 | 27.87 | 15.87 | 10.57 | 47.67 | 25.17 |
| **decoration** | 1.23 | 50.79 | 35.83 | 23.16 | 12.99 | 26.05 | 12.64 |
| **furniture** | 0.87 | 46.82 | 35.91 | 38.41 | 27.93 | 14.76 | 7.19 |
| **medical** | 1.03 | 62.67 | 49.86 | 19.78 | 19.71 | 17.56 | 7.64 |
| **music** | 0.91 | 47.00 | 41.79 | 39.00 | 31.11 | 14.00 | 13.00 |
| **printing** | 1.63 | 55.45 | 51.63 | 9.09 | 8.38 | 35.45 | 18.63 |
| **sports** | 1.19 | 59.79 | 47.54 | 21.11 | 15.63 | 19.11 | 13.90 |
| **tiles** | 0.97 | 55.00 | 40.18 | 22.86 | 16.25 | 22.14 | 16.25 |

**Table 7.42: Performance scores per product category**

Graphically, this leads to the following figures:

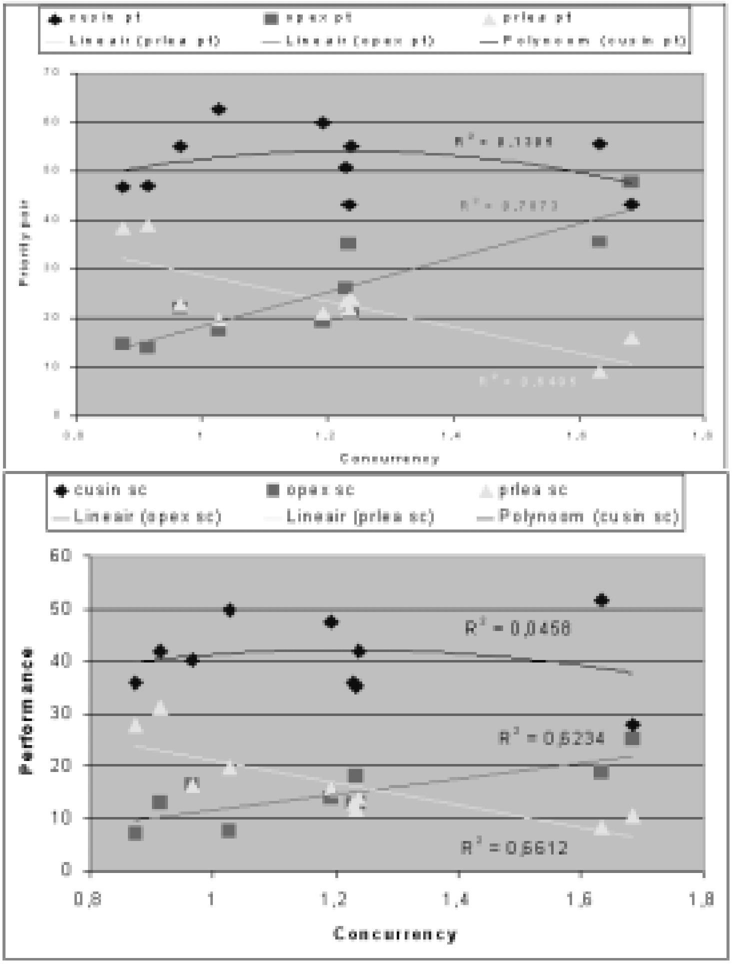



**Figure 7.12a-b: Concurrency vs. priority and performance**[33]

In figure 7.12a the y-axis depicts the priority points given to each of the three disciplines; the x-axis displays the degree of concurrency (as calculated with the formula given in section 7.4.7). In figure 7.12b the y-axis displays the performance scores for the disciplines. The symbols in the figures each represent the average score for one particular discipline for one particular industry (or product type). By using (linear or quadratic)

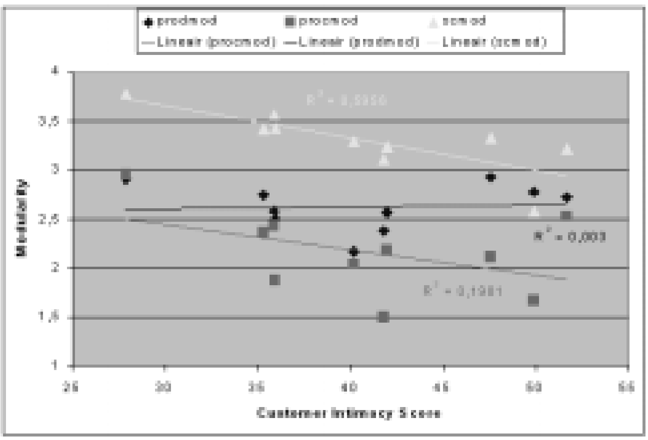
[33] 'Cusin pt' stands for Customer Intimacy points allocated, Opex = Operational Excellence, Prlea = Product Leadership. The sc extension stands for 'score' which indicates the performance on each of the disciplines. The lines through the scatter diagram are linear regression lines; only in the case of Customer Intimacy it is a second-degree polynomial line which gives the best estimate.

regression (ordinary least squares) we are able to draw a line through these symbols. The accompanying values of $R^2$ indicate the strength of the (linear or quadratic) relationship.

The figures confirm the earlier finding about the lack of correlation between concurrency and (degree of) customization, expressed as Customer Intimacy by Treacy & Wiersema (1992). There is however some evidence for a parabolic relation between concurrency and customization, i.e. low and high concurrency values are combined with a low degree of customization, where medium values of concurrency give the highest scores. This is by no means a significant relationship, which is hard to justify theoretically as well.

The most striking finding however, concerns the other two value disciplines Product Leadership and Operational Excellence. It turns out that industries that have a high concurrency in the three dimensions (like construction) exceed in Operational Excellence, while Product Leadership is the value discipline of industries with low concurrency. Furniture and music are examples of the latter type of industries. Still, customer intimacy is the most important objective for these industries, but the correlation between the other two disciplines and concurrency is remarkable and clearly present. We may conclude that effective mass-customization (as combination of Customer Intimacy and Operational Excellence) should be combined with modularity in all three dimensions. A remarkable finding.

Figures 7.13a-c below illustrate the relationships between each of the value discipline scores and the three types of modularity individually.



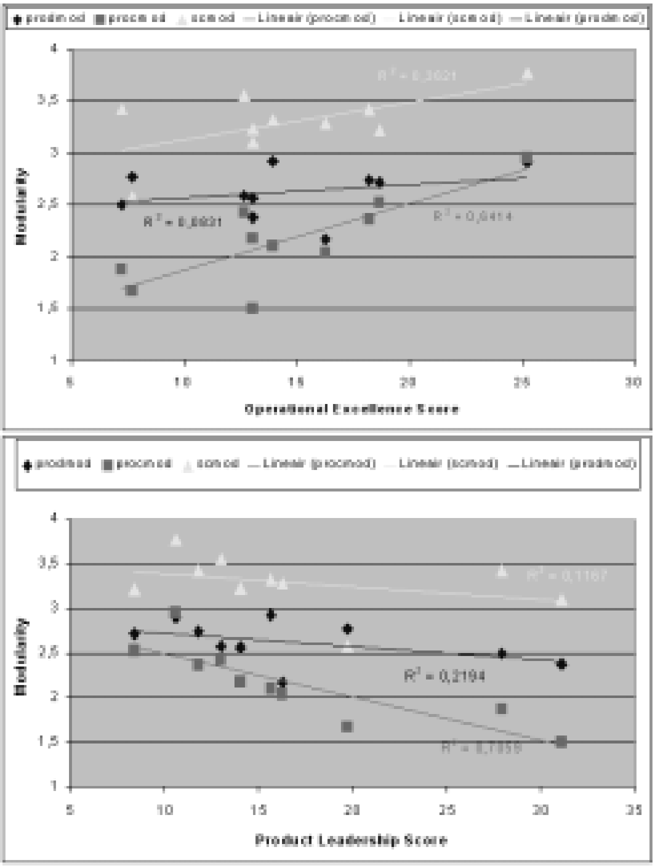



**Figure 7.13a-c: Modularity type vs. Performance scores**

In these figures the x-axes display the scores for each of the value disciplines; the y-axes display the average degree of modularity (product, process and supply chain) per industry (or product) type.

From these figures we learn that the variations in concurrency are especially caused by the variations in process and supply chain modularity. Product modularity does not vary much in relation to performance, indicated by the low values of $R^2$. In particular, Customer Intimacy scores are negatively correlated with supply chain modularity. Product Leadership scores are negatively related with process modularity and Operational Excellence scores are positively related with process modularity and to a lesser extent supply chain modularity.

Can these relationships be explained theoretically? We return to the work of Treacy & Wiersema (1992) who introduced the three value disciplines to shed more light on our findings. We will discuss their views on how organizations can achieve each of these disciplines.

By operational excellence they mean 'providing customers with reliable products or services at competitive process and delivered with minimal difficulty or inconvenience.' (p.84). In their opinion, companies that pursue operational excellence are indefatigable in seeking ways to minimize overhead costs, to eliminate intermediate production steps, to reduce transaction and other "friction" costs and to optimize business processes across functional and organizational boundaries. Dell Computer is introduced by Treacy and Wiersema as a typical example of such a company. Dell has shown its buyers that they do not have to sacrifice quality or state-of-the art technology in order to buy personal computers easily and inexpensively. It sells its computers directly to its customers, it builds to order rather than to inventory and has created a low-cost culture. Building to order, direct sales, eliminating redundant process steps can all be seen as increasing the modularity of both the manufacturing processes and the supply chain. One of the reasons Dell was indeed able to do this, was its highly modular product.

Another less well-known example is General Electric's "white goods" business, which manufactures large household appliances. It has focused on operational excellence in serving the vast market of small, independent appliance retailers. Their main competence is their "virtual inventory", a computer-based logistics system that allows stores to operate as though they has hundreds of ranges of refrigerators in the back room when in fact they have none at all. From the point of the retailer, both its manufacturing processes and its supply chain have become more modular this way. Manufacturing of the appliances can be more dispersed and they are able to select the best supplier by means of a standard inventory information system.

Product Leadership on the other hand is all about striving for producing a continuous stream of state-of-the-art products and services. Companies that want to achieve this, must challenge themselves in three ways, according to Treacy & Wiersema. First, they must be creative. Second, they must commercialize their ideas quickly and third, product leaders must relentlessly pursue new solutions to the problems that their own latest product or service has just solved. Companies excelling in product leadership do not plan for events that may never happen, nor do they spend much time on detailed analysis. Their strength lies in reacting to situations as they occur. In other words these organizations are very similar to Miles & Snow's (1986) dynamic networks. However, Treacy & Wiersema argue that such companies can move fast and take risks because they are organized like a small, entrepreneurial company. Product leaders have a vested interest in protecting the entrepreneurial environment that they have created. To that end, they hire, recruit and train employees in their own mold. They look for people who fit in their own culture. Such a inward strategy, may be denoted as a low-modular strategy. Most of the processes take place in-house and often the same suppliers are used. However, concurrency is still required, albeit on a lower modularity level. Concurrent Engineering may be used to shorten development processes and time to market.

Treacy & Wiersema further state that only a few *maverick companies* have learned how to be master in two. In doing so, they have resolved the inherent tensions between the operating model that each value discipline demands. In our case Mass-Customization is a typical example of such a model, which combines Customer Intimacy and Operational Excellence. What we see in our results is that most of the companies do indeed know how to master the Customer Intimacy model; overall performance scores are high in this respect. However, only the companies that exhibit a high degree of modularity in all three dimensions do also master the operational excellence model and therefore, may indeed be able to mass-customize their offerings to their customers.

To summarize, our findings are to a large extent supported by Treacy & Wiersema. Not only do the results support their findings, they add an interesting modularity and mass-customization perspective to it as well.

### 7.5.5 Conclusions

Based on the previously described analyses we will be able to draw conclusions with respect to our research framework and the formulated hypotheses.

Hypothesis 1:
The higher customer disposition to participate in design, the higher the degree of product modularity.

Customer disposition to participate was divided into customer willingness, customer ability and heterogeneity of demand. In chapter 6 we concluded with respect to this proposition that when the customer's disposition to participate remains below a certain level of high ability and willingness combined with a high heterogeneity in demand then modularity of products is indeed recommendable. In general, the more heterogeneity of demand and the more eager the customer is to participate the more modular a product design may become.

In our survey we found little support for our earlier findings. No direct relation was found between customer disposition to participate and product modularity. We observed however that customer type was a significant variable. Even more, there seems to be a direct effect between customer type and product modularity. Companies that mainly serve other companies as their customers make less use of modular design than business-to-consumer organizations. Most likely, in a business-to-business environment modularity may often be too limited for the customers. They require cut-to-fit products instead of products built from predetermined building blocks.

Hypothesis 2:
The more modular a product design, the more modular process and supply chains will be designed as well.

In chapter we suggested that proposition P2 may be refined by arguing that a concurrent design in three dimensions is easier to accomplish when all modularity levels are low, than when they all three are high. Most likely, the benefits of a highly modular structure are higher as well.

In our survey, we notice that the proposed relationships between the three modularity variables are not very strong. Inter-variable correlations are low and the regression models have low (adjusted) $R^2$s, ranging from 0 to approximately 0.10. These are very low values indeed. To explain this phenomenon we further examined the data and divided them in a number of product categories because the entire dataset was too heterogeneous and respondents too diverse. This division resulted in better support for our proposition, albeit that the method did not possess the same statistical robustness as linear regression. We observe that some industries (such as construction, printing and sports) combine high product modularity with high process and supply chain modularity, while we also see that in some industries (such as furniture and music) all three dimensions are low.

These results, among other things, confirmed our earlier findings in the building industry, with a high degree of modularity in all three dimensions. Especially, when considering that it concerned organizations trying to customize their products. In these circumstances it may be expected that modularity is even more useful.

Explanations for the fact that some industries are more modular than others may have to do with the size, the versatility and availability of standards of these industries. Modular industries are industries where numerous, small organizations are active, such that organizations can choose from a myriad of possible suppliers and product components, where in addition many of these components and suppliers are standardized or use standard procedures. Less modular industries, like furniture and music may be smaller, less diverse and use many more specialized components. Manufacturing processes in these industries may also be less modular, i.e. production takes place at one location, with production and assembly combined. However, these are only 'educated-guesses'. By no means can we theoretically (or even empirically) validate these claims.

Hypothesis 3:
The higher the clockspeed of an industry, the higher the need for a concurrent, modular design of the network will be.

The clockspeed proposition P3 could not be validated within the case study of chapter 6, while it was carried out in one industry only. It was stated that this proposition needed to be further investigated in other industries which have different (higher) clockspeeds than the housing industry. By means of our survey we were able to do this, however, the proposition could not be sufficiently validated on the basis of our results. No direct or moderating relation was found between clockspeed and the modularity or concurrency of the network. Nor does clockspeed seem to influence the relation between concurrency and organizational performance. Therefore, we will decide to remove this variable from our research framework. Measurement of the variable itself, by means of our operationalization described in section 7.4.9, led however to satisfactory results. Further research on clockspeed may be benefited by this.

Hypothesis 4:
The higher the use of ICT customer support tools, the stronger the relation between customer disposition to participate and modular product designs will be.

In the previous chapter we concluded that proposition P4 remained valid. Many of the stakeholders agreed with the usefulness of these systems to increase the ability of the customer in participating in the design of the house. Multi-media systems, virtual reality and the Internet could be helpful in this manner. In our survey we did not find strong evidence for this proposition however. Partly, this may be due to the somewhat difficult operationalization of the variable. Furthermore, this proposition is to a large extent dependent on proposition 1. While we could not validate this latter proposition, the invalidity of an interaction term that moderates another (non-existent) relationship may not come as a big surprise.

Hypothesis 5:
The higher the use of ICT tools for team and supplier communications, the more concurrent the three modularity dimensions will be designed.

Due to the very low degree of the use of ICT systems for team and supplier communications in the housing industry, we were not able to draw any valid conclusions about propositions P5 (and P6) at that moment. We did however indicate numerous possibilities how ICT could indeed support increasingly modular structures, both products, processes and supply chains. Especially when modularity is high in all three dimensions it may be expected that use of ICT is indispensable.

In our survey results, ICT for supplier communications is indeed a moderating variable to the relation between product and supply chain modularity. However, rather surprisingly, we observed that the parameter for this moderator variable had a negative value. This means that the more ICT is used, the weaker the positive relationship between product and supply chain modularity becomes, although it remains a positive relation. In other words for firms with high levels of ICT, a highly modular product design does not necessarily need to be supported by a highly modular supply chain design. A less modular design will also do. This in fact means that we need to falsify proposition P5, at least when it concerns the relation between the concurrency of product and supply chain design.

It was expected that ICT would positively moderate the relation between the different types of modularity, and thus concurrency between the dimensions. For instance, both in literature as in the case study we enumerated numerous possibilities how ICT could support increasingly modular structures, both products, processes and supply chains. Especially when modularity is high in all three dimensions it may be expected that use of ICT is indispensable. The fact that this is not supported by our survey results is therefore unexpected. When we rule out the possibility that the variables measured were not the variables we intended to measure, another explanation needs to be found.

We used the research carried out by Ekering (2000) to come up with an explanation. He argued that IT applications, like EDI, used for communication and information exchange with suppliers do not loosen the mutual coupling but instead tighten it. EDI requires very specific investments (hardware, software, education etc.), numerous agreements on standards and formats and therefore, increase the dependency and binding between the partners (Ekering 2000). These partnerships often have high relation-specificity and switching costs; both features of a low degree of modularity. This may explain the negative (moderating) effect of ICT on the relation between product and supply chain modularity.

Hypothesis 6:
The higher the use of ICT, the more effective a concurrently designed interorganizational business network will be.

When degree of customization is taken as the main performance variable, we do not find sufficient support for proposition P6. In the case of the value discipline variables of Treacy & Wiersema, the significance of an interaction effect is hard to determine. The mainly descriptive approach we used is not well-suited for testing a moderator effect. Therefore, we neither accept nor reject this proposition.

Hypothesis 7:
A concurrent, modular design of products, processes and supply chains increases the performance of interorganizational business networks in general and a mass-customization strategy in particular.

In the previous chapter we suggested that proposition P7 should be refined by mentioning the following. A concurrent design in three dimensions is not always a *guarantee* for increased network performance. Several other factors must be taken into account, not only the fit between customer disposition to participate and modular product design, customer guidance, the use of ICT, but many other factors as well which are not specifically mentioned in our framework. A few building-specific factors are the 'privacy factor' and 'total image of all designs'. These factors were mentioned in sector 6.10. Other factors are 'being experienced with a particular network structure or method' (inexperience as we saw may lead to lower performance), time pressure and so on. Obviously, we were not able to determine firm-specific factors for each industry under investigation in our survey, but we did manage to find a number of interesting results with respect to product/industry type, concurrency and performance.

First, the results confirm the finding of the lack of correlation between concurrency and (degree of) customization, expressed as Customer Intimacy by Treacy & Wiersema (1992). Concurrency in itself may indeed not be a guarantee for customization as we concluded in chapter 6.

The most remarkable finding however, concerns the other two value disciplines Product Leadership and Operational Excellence. It turns out that industries that have a high concurrency in the three dimensions (like construction) exceed in Operational Excellence, while Product Leadership is the value discipline of industries with low concurrency. We learned that the variations in concurrency are especially caused by the variations in process and supply chain modularity. Product modularity does not vary much in relation to performance, indicated by the low values of $R^2$.

We returned to the work of Treacy & Wiersema (1992) who introduced the three value disciplines to shed more light on our findings. Building to order, direct sales, eliminating redundant process steps, setting up a virtual inventory are different means to achieve operational excellence. These features may all be seen as increasing the modularity of both the manufacturing processes and the supply chain. Product Leadership on the other hand is all about striving for producing a continuous stream of state-of-the-art products and services. Treacy & Wiersema argue that such companies can move fast and take risks because they are organized like a small, entrepreneurial company. Product leaders have a vested interest in protecting the entrepreneurial environment that they have created. Such an inward strategy, may be denoted as a low-modular strategy. Most of the processes take place in-house and often the same network partners are used.

Most importantly however, is that we see in our results that only the companies that exhibit a high degree of modularity in all three dimensions do master both the Customer Intimacy as the Operational Excellence model and therefore, may indeed be able to mass-customize their offerings to their customers. This is the major finding of our survey, which confirms not only proposition P7, but sheds new light on the area of Mass-Customization as well.

## *7.6 Model Redefinition*

Considering the findings of the in-depth case study in the building industry together with the results of the survey on business modularity we come to the following adaptations to our research framework. The adaptations are divided in three categories, where each category focuses on a different dependent variable.

### 7.6.1 Factors influencing product modularity

Both in the literature on modularity (e.g., Schilling 2000) and in the case study we found support for our proposition that three customer characteristics determine the (optimal) amount of product modularity. These factors are: heterogeneity of demand, customer ability and customer willingness to participate. We summarized these factors as customer disposition to participate. For each of these factors a positive relationship was assumed with product modularity: the higher customer disposition to participate, the higher product modularity will be. In the survey however, we could not find adequate support for this proposition. Correlations were not significant and in the end, the proposition did not hold. We only found that customer type was a significant variable; even more, there seemed to be a direct effect between customer type and product modularity. Companies that mainly serve other companies as their customers make less use of modular design than business-to-consumer organizations.

What should be the consequences of this? Do we entirely remove these variables from our framework or can a less radical conclusion be drawn? Should other variables perhaps be added to our model?

We suggest the following model:

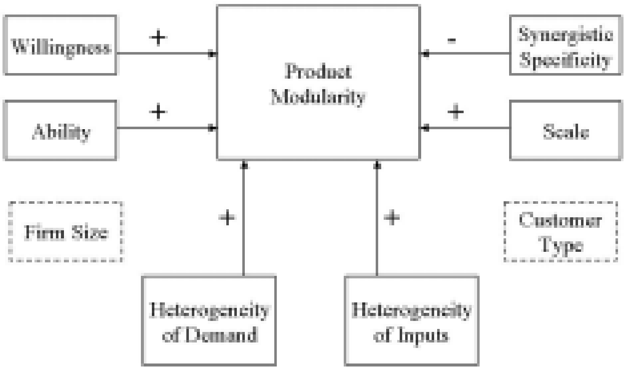



**Figure 7.14: New conceptual model for product modularity**

Although the evidence was not overwhelming, customer ability and willingness remain in the model, just as heterogeneity of demand. Mainly based on our case study findings we expect these three variables to be of importance for the desired degree of product modularity. We added three variables, two of which taken from Schilling (2000). Adding these variables may lead to better explanatory power for the model in explaining why certain products are more modular than others. The first is heterogeneity of inputs. A large heterogeneity of inputs may enable the design of a product into well-defined distinct components, while these components are available in many varieties. If they were not, designing a product in a modular fashion would be less useful. The second is synergistic specificity which may limit the desired degree of product modularity. Synergistic specificity is the phenomenon that certain modules may work better when they are combined than when they are separated. This thus reduces the number of distinct components of a product. The third additional variable to consider is denoted as Scale, which refers to the so-called production scale. It is argued here, and the case study confirms this, that an organization needs a certain scale of its production in order to make modularity worthwhile. In the case an organization wants to offer *real* (or individual) customization, i.e. unlimited freedom for a customer, then modularity is not an option. Modularity is in itself too limited for this purpose. Only when this organization really wants to *mass*-customize, may modularity be useful. Whenever *real* becomes *mass* is hard to determine, but the division needs to be made.

Finally, one needs to control for both firm size and customer type (private persons or businesses). Both variables are probably important moderating variables to several of before mentioned variables and their relationships with product modularity. Which relations are moderated exactly remains uncertain, but we certainly do expect the relation between customer characteristics and product modularity to be changed.

### 7.6.2 Factors influencing modularity in three dimensions

The majority of the housing projects we investigated in chapter 6 exhibited a concurrency of all three business dimensions product, process and supply chain. Often, modularly designed products were accompanied with modular processes and supply chains and vice versa. In the survey we also found sufficient support for this three-dimensional concurrency, albeit that the correlations were not that high. We therefore keep this part of the model as it this, we only add to interaction terms.

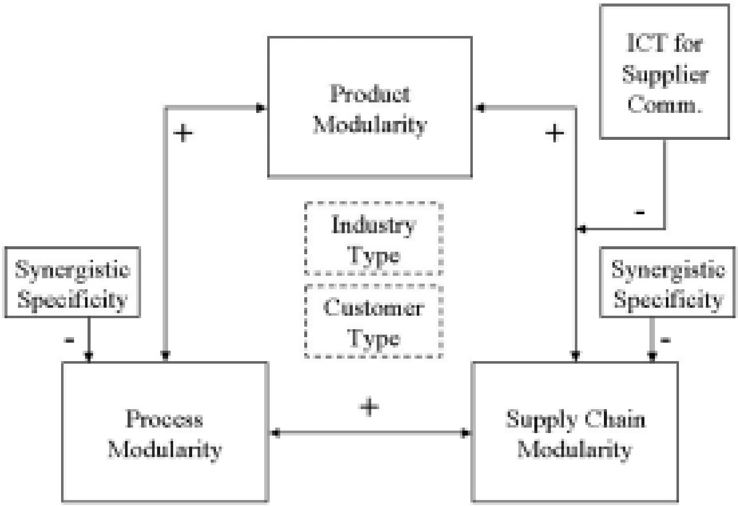



**Figure 7.15: New conceptual model modularity in three dimensions**

The reasoning behind the new model is the following. ICT for communications with suppliers (like EDI) is likely to moderate the relation between product and supply chain modularity. Because of the (surprising) survey result we added a negative sign to this relationship. Theoretically this was hard to explain, while a modular product likely would lead to an increase in the information to be exchanged between the supply chain partners. It was expected that a more modular design of the supply chain can only then be accomplished when an ICT infrastructure supports this. However, often such a structure tightens the coupling between the different partners and thus reduces the modularity. Furthermore, we found that both customer and industry type were important moderating variables for this part of the model. Once again, exactly how these variables moderate the relations between the three modularity types is unsure, but they probably do have effect.

Just as in the product modularity model, we added synergistic specificity to both process and supply chain modularity. Synergistic specificity is the phenomenon that certain modules may work better when they are combined than when they are separated. It may be expected that processes and supply chains are subject to this phenomenon as well.

### 7.6.3 Factors influencing organizational performance

The most significant finding in the housing industry case was the fact that designing a network which possesses high modularity in all three dimensions is more difficult than a network where all dimensions are less modular, i.e. integral. However, when a network is successful in the former approach, benefits can also be higher, customers more satisfied etc. In the end, this may lead to a successful Mass-Customization strategy. In the survey we focused on two types of performance measurements: degree of customization and achieving particular predefined objectives (based on the three value disciplines of Treacy & Wiersema 1992). In the case of the former performance variable, we did not find any significant relation between concurrency in the three business dimensions and performance. We concluded that a concurrent design in three dimensions is by no means a guarantee or a requisite for product customization or increased freedom of design for the customer. This lack of correlation between concurrency and (effective) customization was further confirmed by our second performance analysis. Treacy & Wiersema's Customer Intimacy showed no direct correlation with concurrency in three dimensions. All organizations had high scores on this objective, which is no surprise while we surveyed customizing organizations in particular.

However, we did find interesting dependencies between concurrency and the other two value disciplines: product leadership and operational excellence. It turns out that industries that have a high concurrency in the three dimensions (like construction) exceed in Operational Excellence, while Product Leadership is the value discipline of industries with low concurrency. We learned that the variations in concurrency are especially caused by the variations in process and supply chain modularity. Product modularity does not vary much in relation to performance, indicated by the low values of $R^2$.

The following figure graphically illustrates before mentioned discussion and presents the variables and their mutual relationships.

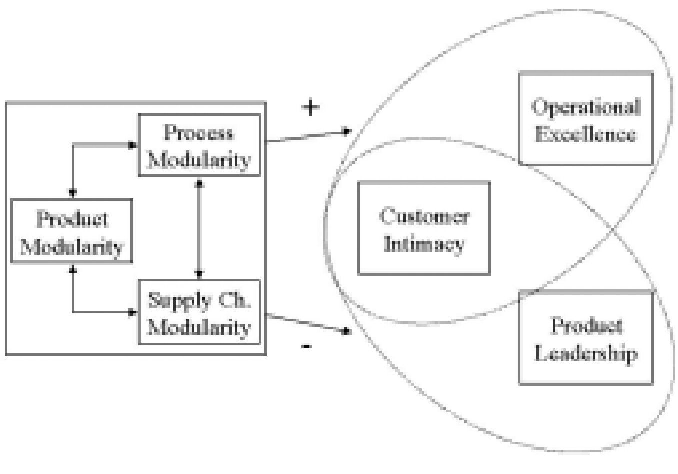



**Figure 7.16: New modularity-performance conceptual model**

# RESEARCH MODULE 4:

# CONCLUSIONS

## CHAPTER 8 CONCLUSIONS AND FURTHER RESEARCH

### *8.1 Conclusions*

Coming at the end of this dissertation it is time for a reflection. We started out the research with Modular Network Design, the process modeling approach developed by Hoogeweegen (1997), which incorporated an empirical descriptive modeling perspective with a conceptual prescriptive vision on how interorganizational business processes should be designed. Hoogeweegen developed this approach initially to assess the impact of EDI on business networks. During application of the approach and further development it was hypothesized to be a useful model for many purposes. Our first research objective was to validate this claim and investigate the validity of the approach.

The first research question was formulated as follows:
**How and to what extent does MND support the design of customized cost-efficient business networks?**

To achieve the research objective and to answer this first research question we translated MND into a Decision Support System and applied this DSS in two empirical settings, both in the air cargo sector. In this way we were able to draw a number of conclusions about the validity of the approach. The following conclusions provide the answer to the research question on MND:

- MND supports managers in a very conceptual manner by offering a new perspective on the 'art of doing business'. This new art of doing business concerns the design of business networks that take the requirement of the customer as starting point and subsequently are set up temporarily to fulfill this requirement.
- Combining a strategic vision with a very detailed operational process assessment however, often leads to confusion and indefiniteness about the precise objectives and range of application of the model.
- The focus of an application of MND within a business network (or a single organization) should always be on the requirements of the end-customer.
- Only small, incremental redesign scenarios can be assessed, to ensure sufficient reliability and general validity of the model and its application.

Most importantly, these findings indicated that MND wavers between two opinions: either being an analytic assessment tool for business process calculation and visualization or representing a conceptual theory on a specific business paradigm, i.e. mass-customization, modularity and dynamic networking.

Generalizing, one may argue that one needs to be careful in developing completely new redesign support tools. At the moment, a vast library of existing tools and methods is available (see Kettinger et al. 1997) and most likely, one can find a suitable tool in this library – or combination of tools – that may be useful, with perhaps some small modifications, for the objective at hand. In the exceptional case that there is no method available one needs to find the right balance between a dedicated tool and a generic one. Hoogeweegen decided to design a very generic tool for a very specific objective: assessing the impact of EDI. This imbalance led to much confusion and redundancy during the analyses.

In the end, this wavering between two opinions led us to conclude that both perspectives should be developed further independent of each other. We decided to follow the latter – conceptual prescriptive - perspective and went on to develop a more profound theoretical framework on business modularity. Although Modular Network Design takes modularity as one of its starting points, the actual theoretical justification and application of the concept proved to be insufficient and a little ambiguous. Therefore, we took up the glove of further investigating the *pros and cons* of using modularity in an (inter-)organizational business environment.

In this respect, the following research question was asked:
**How can modularity enhance the performance of business networks?**

An extensive literature study was the starting point of our analysis. By means of this study we tried to come up with a clearer and better demarcated definition of modularity, its possible advantages and disadvantages and defined a number of factors that could influence the (optimal) degree of modularity of a system (like a product or a business network).

The following features for determining the modularity of a system were defined:

- Distinctiveness of components
- Loose coupling between modules; tight coupling within modules
- Clarity of mapping between functions and components
- Standardization of interfaces
- Low levels of coordination (self-organization; coordination embedded in the architecture)

By means of these features we were able to come up with a definition of modularity:
*A system is modular when it consists of distinct (autonomous) components, which are loosely coupled with each other, with a clear relationship between each component and its function(s) and well-defined, standardized interfaces connecting the components, which require low levels of coordination.*
The modularity of a system decreases when one or more of these conditions fail to hold.

The literature analysis led to a preliminary version of a conceptual model (or research framework). This model was the starting point for developing a theoretical framework on business modularity in three dimensions of doing business: designing products, processes and supply chains. This distinction in three dimensions was one of the fruitful legacies of Modular Network Design that we used for our framework. The central proposition of our framework was that a concurrent, modular design increases the performance of interorganizational business networks in general and a mass-customization strategy in particular. In other words we expect that organizations that analogously design their business network in a modular fashion in all the previously mentioned dimensions will perform better than organizations that do not. That is, organizations that use a more integral or asynchronous approach. Our theoretical framework also incorporated a number of other contingent factors that either influenced the individual variables of our model (like product modularity or performance) or influence the relationships between these variables. The most important of these are the use of ICT and the role of the customer in the design.

We undertook the first explorative investigation of the usefulness and validity of our framework by means of a multiple-embedded case study in the Dutch Housing industry. In particular, we focused on an experimental housing project called *Gewild Wonen*. In this project, the objective of the initiators was to develop and build a significant number of houses where the customer's influence on the design was bigger than in regular, comparable housing projects. We investigated to what extent the stakeholders used modularity to achieve their goals. The results of this study were very satisfactory in relation to our research framework. We were able to validate our initial propositions and rephrase them where necessary.

The following conclusions were drawn from the case study in the housing industry:

- The houses designed in the *GW-project* were more modular than houses built in regular housing projects. Most of the architects decided to introduce modularity on the level of the exterior, the most rigid level of house design, which determines the size and shape of the house. The architects however did, for instance, not go as far as designing already predetermined and premanufactured bedroom- or living room-modules.
- In order to achieve modularity on the exterior house level, manufacturing processes had to become more modular as well. That is, builders needed to use production techniques that actually allowed for building of these more modular homes. This meant that the more integral techniques, such as concrete building, were replaced by more flexible techniques.
- When comparing the different individual *GW* sub-projects with each other a positive relationship was found between three-dimensional business modularity and organizational performance. A concurrent design in all three dimensions often leads to better performances[34], at least when there is a fit between the customers' requirements and the network structure and capabilities.
- In most of the sub-projects, whenever both product and process modularity were low, the supply chain did not require many changes compared to normal. This was in these cases very successful, at least when the customer's disposition to participate was low as well.
- A concurrent design in three dimensions is easier to accomplish when all modularity levels are low, than when they all three are high.

[34] In the case study defined as a combination of satisfied customers, financial gains and living up to the objectives of the *Gewild Wonen* project.

The findings of this study were further used in the last step of the research project: a survey among numerous customizing organizations, dispersed all over the world. The heterogeneity of responses from these organizations, with diverging products, organizational structures and performance indicators unfortunately led to a decrease of our earlier optimism about the validity of the research framework. A number of the proposed relationships could not be confirmed by means of the survey. Statistical methods such as Structural Equation Modeling and Linear Regression, which are normally used for analyzing surveys like this, showed a low degree of fit of our entire model and the individual relationships also failed to hold in several circumstances. As already mentioned, the high heterogeneity of the respondents compared to our very generically defined framework was the probable cause of this drawback. Nevertheless, we could confirm several propositions and the results gave interesting, unexpected insights into the relation between business modularity and performance.

From the survey on business modularity we learned the following:

- We observed that some industries (such as construction, printing and sports) combine high product modularity with high process and supply chain modularity, while we also see that in some industries (such as furniture and music) all three dimensions are low.
- No direct or moderating relation was found between clockspeed and the modularity or concurrency of the network. Nor does clockspeed seem to influence the relation between concurrency and organizational performance.
- In our survey results, ICT for supplier communications is indeed a moderating variable to the relation between product and supply chain modularity. However, rather surprisingly, we observed that the parameter for this moderator variable had a negative value. This means that the more ICT is used, the weaker the positive relationship between product and supply chain modularity becomes.
- The most remarkable finding concerns the two value disciplines Product Leadership and Operational Excellence. It turned out that industries that have a high concurrency in the three dimensions (like construction) exceed in Operational Excellence, while Product Leadership is the value discipline of industries with low concurrency. We learned that the variations in concurrency are especially caused by the variations in process and supply chain modularity.
- We see in our results that only the companies that exhibit a high degree of modularity in all three dimensions do master both the Customer Intimacy as the Operational Excellence model and therefore, may indeed be able to mass-customize their offerings to their customers.

Eventually, we were able to reformulate our research framework based on these findings and subsequently answer our second research question. The answer to this question 'How can modularity enhance the performance of business networks?' may be formulated as:
Modularity can enable and support a mass-customization strategy of networks of organizations. Its use seems to be most effective and successful when the three business dimensions product, process and supply chain are designed concurrently, i.e. all three dimensions exhibit the same degree of modularity. The optimal degree of modularity is, among other things, subject to the customer's disposition to participate and the industry type (e.g., the versatility and availability of standards within an industry, the size and number of organizations active in an industry).

Finally, one may ask whether there is a way to combine the research on MND with the research on business modularity. It is obvious that the latter was strongly based on the former, but can MND also benefit from the modularity research? In all modesty we may now argue, after the analyses discussed in the third research module that we developed the conceptual prescriptive part of MND into a better demarcated and more sound theory. Not only did we operationalize the constructs of the conceptual prescriptive MND in more detail, we also found empirical evidence for most of the relationships defined in this prescriptive model. The straightforward claim of MND that modularity is always good and should be aspired, could be differentiated and refined by stating that the customer's disposition to participate should be taken into account, just as the notion that a concurrent, modular business network design is far more difficult to achieve than a less modular design. Furthermore, a balance needs to be found between modularity of the three business dimensions products, processes and supply chains.

Based on these findings we may be able to develop a new approach that combines both research efforts. This new approach (or theory) may be denoted as 'Three-Dimensional MND' to indicate the link between both of our research efforts and Hoogeweegen's. In section 8.4.1 we elaborate further on this approach.

Reaching the closure of this dissertation, there are a number issues that we still want to discuss. First, we want to elaborate on the theoretical and practical implications of our research effort. What did we contribute to management theory and how can practitioners learn from our findings? Section 8.2 discusses the theoretical implications, section 8.3 the practical ones. The second issue is the issue of future research. In section 8.4 we elaborate on these newly defined questions and discuss how they may be investigated.

## *8.2 Theoretical implications*

With respect to the theoretical side of this thesis, the research and its conclusions described in this thesis may have implications for a number of research areas. They are described below.

### 8.2.1 Validating Decision Support Methods and Tools

At the end of the '80s and early '90s when desktop PC's became more and more used, especially in work environments, many research efforts were carried out focusing on the effectiveness of these PC's and their software. In particular, one focused on the effectiveness of Decision Support and Information Systems. DeLone & McLean (1992) extensively described the search for relevant variables that influenced the success of these systems and more important, variables that measured their effectiveness. We thankfully made use of their work and that of others, in particular Finlay & Wilson (1997), who developed a comprehensive validation model for Decision Support Systems. We operationalized their model and applied it on Modular Network Design. In combination with the work on BPR methods and techniques of Kettinger et al. (1997), this proved to be a very fruitful method to analyze the validity of an approach like MND. Kettinger et al. (1997) specifically focused on BPR related tools and methods and their merits to support a BPR project. Combining this perspective with the more general view on supporting systems from Finlay & Wilson (1997) led at the same time to a generalization of the Kettinger model and a specific application of the Finlay & Wilson model.

In this manner, we were not only able to make various statements about the usability, reliability or robustness of the MND method, we also learned a great deal about the (validity of the) theories developed by both Finlay & Wilson and Kettinger et al. For instance, Finlay & Wilson did not present a worked out methodology to determine the value of each of the validity types of their model. They only state: 'A *validity framework* needs first to be developed, to be followed by the development of a *validation methodology* contingent upon the exigencies of the situation in which the DSS is designed, implemented and used.' (Finlay & Wilson 1997:171) By using the work of Kettinger et al. (1997) and Hoogeweegen (1997) we were able to contribute to their work by designing a more worked out validation methodology.

### 8.2.2 Defining and measuring modularity

One of our early observations of this thesis was the lack of a clear and useful definition of modularity. Sometimes the features of modularity were mistaken by its effects. For instance, Schilling (2000) defines modularity as the ease of separation and recombination, while separation and recombination are principally effects of a modular design. On the other hand, we saw that concepts like loose coupling, granularity and integration were often confused with or otherwise ambiguously related to modularity. Furthermore, confusion existed over concepts like elements, modules, entities, chunks etc.

In chapter 5 we have tried to give a structured overview of many of these definitions, views and perspectives and tried to make a well-argumented choice for a particular definition of modularity. This definition consisted of a number of specific features, which not only should be applicable to products, but to processes and supply chains as well. We may even argue that our definition can be applied to other systems as well. Furthermore, we have tried to come up with an operationalization of this definition, which was used in our business survey, described in chapter 7.

Both the definition and the operationalization may be useful for other research efforts on modularity in general and business modularity in particular.

### 8.2.3 Why and how modularity

Schilling (2000) and Worren et al. (2000) already presented a model to explain why some systems are more modular than others and why the application of modularity may be useful for organizations. We have tried to add more insight to this question, partly building upon their work. Furthermore, we specifically focused on three business dimensions where modularity may be advantageous. The work of Fine (1998) was particularly useful in this manner. He came up with the idea that a concurrent design in all three dimensions may be most effective. We added a modularity and mass-customization perspective to Fine's theory. By means of the case study and the survey, we showed that three-dimensional modularity indeed improves performance in particular circumstances.

### 8.2.4 Modularity and (mass-)customization

Quite often modularity is seen as *the* enabler for mass-customization. Combining the work of organization researchers such as Schilling, Sanchez and Worren, the work on product development from Ullrich and his colleagues and Baldwin & Clark and the work on mass-customization from Pine we were able to both broaden and refine this view. Where most mass-customization lecturers only speak of product modularity we showed that process modularity and supply chain modularity need to be considered as well. On the other hand, in both the housing case (chapter 6) as well as the survey (chapter 7) it was found that modularity is not the only solution for mass-customization; it is not even compulsory. Sometimes, modularity may be too limiting or overdone. Simply offering a limited set of basic variants to the customer, may just as well be a effective form of mass-customization in itself.

### 8.2.5 Clockspeed

Although the clockspeed variable was not the most significant variable in our analyses, we still managed to come up with a useful operationalization of the variable, strongly relying on the work of Mendelson & Pillai (1998). Where Mendelson & Pillai used their measurement instrument in the electronics industry only, we extended its use to other industries as well. In this manner, their instrument could be validated in a more general setting.

Comparing our results with Mendelson & Pillai (1998), two remarkable facts were found. First, the majority of the respondents indicated a rise in the prices of input materials over the past five years. Mendelson & Pillai found however, that most respondents had to deal with decreasing input prices. Second, Mendelson & Pillai found a strong correlation between the three items - life-cycle, prices of input materials and product freshness - where we only found a very low degree of correlation. This could mean that their items are really electronics-industry specific and that a more generic operationalization is required, applicable to other industries as well.

### 8.2.6 Master of Two: Three-Dimensional Modularity as a Value Discipline

Finally, our research may have implications on Treacy & Wiersema's (1992) Value Disciplines. Not only did we add a measurement instrument to this theory, we also found an interesting relationship between modularity in three dimensions and these disciplines. In fact, what Treacy & Wiersema describe as being Master of Two, i.e. being master of two of the disciplines at the same time, seems to be possible for organizations that concurrently design their products, processes and supply chains. A modular design of all three dimensions is likely to be congruent to being master of (or at least skilled at) both Customer Intimacy and Operational Excellence. This offers interesting new insights in and applications of the work of Treacy & Wiersema.

## *8.3 Practical implications*

Practitioners reading this thesis may be wondering what this research could mean for their own day-to-day business. The following sections elaborate on possible practical implications of this thesis.

### 8.3.1 Choosing the right redesign approach

Although the BPR and BNR *hype* seems to be over almost completely, it is imaginable that many organizations keep on struggling with the way new technologies, new markets or even new type of customers should be dealt with. How to profit from the new developments as much as possible, how to avoid falling behind to the competition and how to avoid large investments that do not pay off in the end? Such complex decision making requires adequate support, for instance, by means of analytical tools and methods.

So many consulting organizations and research institutes are on the market nowadays, trying to sell their own methods that it may be a new problem in itself to decide which method to use. The validation framework we developed in the second research module (see section 5.6 in particular) may be helpful in this manner. It stresses the criteria one should be keen on when evaluating a method and it gives a number of guidelines for choosing the right method for the situation at hand. Such guidelines include the radicalness of a project, its structuredness and its potential for IT enablement.

### 8.3.2 Modularity matters

What we really tried to show in this thesis, is that modularity matters. Assessing ones own organization and surrounding business network from a modular perspective may shed new light on its structure and performance. We have enumerated a number of reasons why organizations should employ a modular design and how this could be done. Practically, this means that organizations will be able to consider whether a modular approach is useful in their own environment. The characteristics of modularity, given in chapter 5, may be useful guidelines in setting up a more modular (inter-)organizational structure.

Furthermore, our focus on a concurrent design in three dimensions, stresses the need for a balanced design. That is, a highly modular product structure should not be combined with a mere integral supply chain and vice versa. One needs to find the right balance between the three dimensions.

### 8.3.3 The difficult path to mass-customization

From the case study analysis in the building industry we learned that the path to successful mass-customization is a difficult one. Especially when an industry has been used to the traditional, rigid structure focused on mass-production and fixed procedures, the transition can be hard and unpleasant. Organizations in other sectors may learn from the experiences of the building industry described in chapter 6. For instance, one may learn that the way customers are (or at least should be) approached and treated differs significantly from ordinary practice. Or one may learn that the existing production techniques may be unsuited for the flexibility and variety required by the customer. One may also find out that the traditional supply chain structure needs rigorous modification, focused on responsiveness and innovation. All in all, we hope that this chapter provides useful insight in the caveats and problems that one may encounter during the transition and moreover, that it may help in solving these as well.

## *8.4 Directions for further research*

Finally, we want to enumerate a number of research directions that may be most interesting to focus on the coming times. We already introduced a number of directions in section 4.8 at the end of research module 2. In research module 3 we investigated one of these directions in detail, i.e. business modularity. This time we add a few more and elaborate on of the directions of section 4.8 a little further, i.e. modeling mass-customization and modularity.

### 8.4.1 3D-MND: Modeling mass-customization

In several earlier sections we argued that MND may be benefited by a more clear-defined modeling objective. The current state of the approach is as such that it wavers between two opinions: either being an empirical descriptive approach or a more conceptual prescriptive one. We suggest to carry out more research on the development of the empirical descriptive part of MND, especially focusing on modeling and assessing mass-customization strategies.

When we try to combine the research on business modularity with the research on the empirical descriptive MND, the operationalization of the variables into items and questions used in the survey may be the most useful part of the third research module. An important conclusion with respect to this part of MND was the fact that MND itself does not give guidelines for the level of detail of the analysis. Confusion and indefiniteness about the precise objectives and range of application of the model often lead to an overly detailed operational process assessment. One needs to precisely define these objectives and subsequently the level of detail and the range of the application. The questions referring to Treacy and Wiersema's (1992) value disciplines may be useful in determining the right objective and subsequent range and detail of the application. When, for instance, the survey indicates a strong organizational preference for Operational Excellence, the MND analysis should be focused on detailed cost and throughput time assessment. However, when customer intimacy is far more important one should better focus on the service elements and the link with the back-office (production elements and process modules). The cost and throughput time analysis can be less detailed in that case.

The work on business modularity may further be used for operationalizing mass-customization concepts such as modularity and customer disposition to participate. One should also include clearly defined performance measurements. Such an approach may support organizations in deciding whether or not to pursue a mass-customization strategy, based on the characteristics of their customers, their own (inter-) organizational structure and technological readiness.

### 8.4.2 Mass-customization in the building industry

During our analyses in the building industry it turned out that the current developments in the building industry are very interesting and challenging and that they require much more investigation. Building organizations in the Netherlands have been used to many years of mass-producing standard houses with little customer influence. The government has had a great impact on the industry as well with numerous regulations, requirements and restrictions. We observed that introducing mass-customization in the building industry is attended by many problems and challenges. For instance, the earlier introduced (section 6.10.2) privacy-factor is a factor to be reckoned with, which is unique to the building industry. The same holds for the requirement that their should be some coherence in all individual designs. No other industries need to live with such restrictions. Governmental policies further limit the current developments. For instance, the *Bouwbesluit* (building resolution) is not able to deal with the design of modular housing systems, out of which numerous different houses may be constructed, all based on the same basic system. The Bouwbesluit dictates that each house design needs to be judged and evaluated individually.

The organizational difficulties may be the most challenging to investigate further in combination with the possible enabling role of ICT in the building industry. The next couple of years the industry needs to redesign itself significantly. For researchers from multiple backgrounds (such as management science, architecture, information systems, policy and engineering), it may be worthwhile developing a multi-perspective research program specifically focused on the building industry and the contemporary developments it is facing.

### 8.4.3 Multi-industry comparison

In section 7.5.3, when discussing the survey results, we observed that some industries (such as construction, printing and sports) combined high product modularity with high process and supply chain modularity, while we also noticed that in some industries (such as furniture and music) all three dimensions were low. We wondered what could be the theoretical rationale behind the fact that some industries possessed more modular characteristics than others. Why is the construction industry more modular than the music or furniture industry? It was concluded that this probably has to do with the size, the versatility and availability of standards of the industries. In some industries numerous small organizations are active, such that other organizations can choose from a myriad of possible suppliers and product components, where in addition many of these components and suppliers are standardized or use standard procedures. Furniture and music industries may be smaller, less diverse and use many more specialized components. The impact of ICT on the design phase may be less strong. Manufacturing processes in these industries may also be less modular, i.e. production takes place at one location, with production and assembly combined.

However, these were only 'educated-guesses'. By no means can we theoretically (or even empirically) validate these claims. More research focused on comparing industries in this respect and explaining why certain differences exist, needs to be carried out first. This could be done by repeating the survey on a larger scale, after some of the scale reliability issues have been resolved. This time, one does not need to focus on customizing organizations only. One could, for instance, select organizations from four different industries and compare the results with each other.

Note however, that before such a survey can be carried one needs to develop a theory or conceptual model first that tries to explain – theoretically – why we may expect more modular structures in some industries than in others. Next to our own theory on business modularity, Schilling's (2000) theory on modularity may be very useful in this respect as well.

### 8.4.4 Modularity and ICT

In our survey results, ICT for supplier communications turned out be a significant moderating variable to the relation between product and supply chain modularity. Rather surprisingly, we observed that the parameter for this moderator variable had a negative value. This means that the more ICT is used, the weaker the positive relationship between product and supply chain modularity becomes, although it remains a positive relation. This meant that we needed to falsify proposition P5. This finding contradicts the theoretical findings that state that ICT is indispensable for using modularity due to its large (informational) complexity. Further research on the connection between modularity and ICT may shed more light on this surprising result.

### 8.4.5 Modularity and the Development of Software Systems

In the development of software systems modularity is a very important design parameter. For instance, the Unified Modeling Language (UML) is a language for specifying, visualizing, constructing, and documenting the artifacts of software systems, as well as for business modeling and other non-software systems. UML is closely related to Object-Oriented modeling techniques, which extensively use the concepts of modularity, to ensure interoperability, standardization and a formal basis for understanding the modeling language. We shortly mentioned the developments in the software development and OO-tools industry in section 5.2.3 but we did not investigate these developments in detail.

We also mentioned the Model Driven Architecture (MDA) in section 4.6.1. MDA supports evolving standards in application domains as diverse as enterprise resource planning, air traffic control and human genome research. It separates the fundamental logic behind a specification from the specifics of the particular middleware that implements it. This allows rapid development and delivery of new interoperability specifications that use new deployment technologies but are based on proven, tested business models. Organizations can use MDA to meet the integration challenges posed by new platforms, while preserving their investments in existing business logic based on existing platforms. It would definitely be interesting and worthwhile to further explore the experiences and formal design rules of this industry and to extrapolate these rules to generic business processes and customized business networks.

### 8.4.6 Modularity and becoming Master of Two

By means of the business survey we were able to expose an interesting and promising relationship between modularity and Treacy & Wiersema's (1992) Value Disciplines. The method used for this purpose however, did not possess much statistical rigor. It was a mere descriptive and graphical approach. It may be worthwhile investigating the relationship between three-dimensional modularity and being Master of Two further. This could be done by carrying out various in-depth case studies at organizations and business networks that are supposed to be Master of Two and measure the degree to which they apply a modular design. Treacy & Wiersema already mention a few in their work, but one can probably think of many more. Good examples may be Dell and Cisco which were brought forward in the first chapter of this dissertation.

Now that we have come back to the beginning, this seems to be a suitable moment to finish this thesis. Thank you for your interest.

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# APPENDIX 1: RESULTS DISTRIBUTION CASE

## *A1.1 Current situation*

In this first section the results are presented for all orders in the current situation. This includes total throughput and critical time per order as well as per organization involved. Furthermore, operation costs for each order are given as well. Due to reasons of confidentiality the names of the organizations involved are fictitious.

### A1.1.1 Times

| Order no. | Total time[35] | Critical time | Distrib'n | BU PS | BU CH | Cargo NL | Cargo US | Whiz Aids | Parcel | Consignee |
|---|---|---|---|---|---|---|---|---|---|---|
| 1a | 1605 min | 1516 min. | 20 | 22 | 59 | 151 | 48 | 44 | 372 | 4 |
| 1b | 1589 min | 1498 min. | 20 | 22 | 47 | 167 | 32 | 53 | 372 | 8 |
| 2a | 245 min | 180 min. | 8 | 20 | 47 | 167 | | | | |
| 2b | 263 min | 197 min. | 8 | 20 | 59 | 151 | | | | |
| 3a | 244 min | 179 min. | 8 | 19 | 47 | 167 | | | | |
| 3b | 244 min | 179 min. | 8 | | 47 | 167 | | | | |
| 4 | 25 min | 25 min. | | | | | | | | |
| 5 | 867 min | 867 min. | | | | | | | | |
| Total | 5082 min | | 72 min | 103 min | 306 min | 970 min | 80 min | 97 min | 744 min | 12 min |
| | | | | | | | | | | |
| **Order no.** | | | **Forwarder** | **Shipper1** | **Shipper2** | **Airline** | **BU 747** | **Aviation Distr.** | **Courier** | **Aviation** |
| 1a | | | 20 | 25 | | | | | | 840 |
| 1b | | | 25 | 3 | | | | | | 840 |
| 2a | | | | | 3 | | | | | |
| 2b | | | | | 25 | | | | | |
| 3a | | | | | | | 3 | | | |
| 3b | | | | | | | 3 | | 19 | |
| 4 | | | | | | | | | 25 | |
| 5 | | | | | | 22 | | 845 | | |
| Total | | | 45 min | 28 min | 28 min | 22 min | 6 min | 845 min | 44 min | 1680 min |

**Table A1.1: Total times per organization in the 'current situation'**

In table A1.1 above, total time is the cumulative time of all process modules that are carried out during the order process. Critical time is the total time of all process modules on the critical path: the longest path (from start to finish) in the process module network. Total times per organization are listed in the individual cells.

We can see that Cargo NL consumes most of the process time of the Dutch trajectory. Especially, the processing of the goods takes a lot of time. The Customs trajectory consists of two distinct phases: pre arrival notification and picking up and releasing the goods. Only the last trajectory lies on the critical path. The amount of time used by BU PS strongly depends on the distance to be traveled. Distribution itself only takes care of the status messages.

### A1.1.2 Costs

An important part of the total costs is caused by the air transport from the Netherlands to the US and vice versa. The real costs of this process module are at the moment very hard to estimate and therefore, the air transport costs have not been included in the table below.

[35] As a percentage of the total throughput time for all 5 modeled orders.

For each order the total costs have been listed and costs are calculated per organization involved. Remember that all organizational costs are based on the same resource tariffs.

| Order no. | Total costs | Distrib'n | BU PS | BU CH | Cargo NL | Cargo US | Whiz Aids | Parcel | Consignee |
|---|---|---|---|---|---|---|---|---|---|
| **1a** | ƒ 871.45 | 22.40 | 24.93 | 72.46 | 169.61 | 52.72 | 49.00 | 425.18 | 4.65 |
| **1b** | ƒ 848.21 | 22.40 | 24.93 | 53.97 | 186.66 | 35.37 | 59.60 | 425.18 | 9.05 |
| **2a** | ƒ 275.78 | 8.95 | 22.65 | 53.97 | 186.66 | | | | |
| **2b** | ƒ 302.17 | 8.95 | 22.65 | 72.46 | 169.61 | | | | |
| **3a** | ƒ 274.63 | 8.95 | 21.50 | 53.97 | 186.66 | | | | |
| **3b** | ƒ 274.63 | 8.95 | | 53.97 | 186.66 | | | | |
| **4** | ƒ 28.36 | | | | | | | | |
| **5** | ƒ 990.57 | | | | | | | | |
| **Total** | ƒ 3865.80 | ƒ 80.60 | ƒ 116.66 | ƒ 360.80 | ƒ 1085.86 | ƒ 88.09 | ƒ 108.60 | ƒ 850.36 | ƒ 13.70 |
| | | | | | | | | | |
| **Order no.** | | **Forwarder** | **Shipper1** | **Shipper2** | **Airline** | **Shipper3** | **Aviation Distr.** | **Courier** | **Aviation** |
| **1a** | | 22.00 | 28.50 | | | | | | |
| **1b** | | 27.50 | 3.55 | | | | | | |
| **2a** | | | | 3.55 | | | | | |
| **2b** | | | | 28.50 | | | | | |
| **3a** | | | | | | 3.55 | | | |
| **3b** | | | | | | 3.55 | | 21.50 | |
| **4** | | | | | | | | 28.36 | |
| **5** | | | | | 24.95 | | 965.62 | | |
| **Total** | | ƒ 49.50 | ƒ 32.05 | ƒ 32.05 | ƒ 24.95 | ƒ 7.10 | ƒ 965.62 | ƒ 49.86 | |

**Table A1.2: Total costs per order and per organization**

## *A1.2 Alternative designs*

Four different alternative designs have been defined:

1. Tracking and tracing is carried out electronically with EDI, instead of by paper and fax;
2. The preparation of the AWB is carried out electronically by Customs Handling, instead of on paper by the shipper;
3. The trucks from VD, a department within Distribution, are replaced by trucks from YT, another department within the same mother company, not directly belonging to Distribution.
4. The number of trucks (VD) and forklift trucks available are increased. This alternative builds forth on the previous example with limited resources.

In the first three alternatives all resources still have unlimited capacity. Only for the third alternative this assumption is removed.

### A1.2.1 Alternative 1: Tracking and tracing

The table below consists of the results of the first alternative scenario, electronic tracking and tracing. The results of the current situation are included to observe the time and cost savings.

| Order | Total time | | | Critical time | | | Costs | | |
|---|---|---|---|---|---|---|---|---|---|
| | Current | Altern. | Savings | Current | Altern. | Savings | Current | Altern. | Savings |
| **1a** | 1605 min | 1581 min | 24 min. | 1516 min | 1510 min | 6 min. | ƒ 871.45 | ƒ 842.31 | ƒ 29.14 |
| **1b** | 1589 min | 1565 min | 24 min. | 1498 min | 1489 min | 9 min. | ƒ 848.21 | ƒ 819.09 | ƒ 29.12 |
| **2a** | 245 min. | 236 min. | 9 min. | 180 min. | 175 min. | 5 min. | ƒ 275.78 | ƒ 264.86 | ƒ 9.92 |
| **2b** | 263 min. | 254 min. | 9 min. | 197 min. | 197 min. | 0 min. | ƒ 302.17 | ƒ 291.23 | ƒ 9.94 |
| **3a** | 244 min. | 235 min. | 9 min. | 179 min. | 174 min. | 5 min. | ƒ 274.63 | ƒ 263.71 | ƒ 9.92 |
| **3b** | 244 min. | 235 min. | 9 min. | 179 min. | 174 min. | 5 min. | ƒ 274.63 | ƒ 263.71 | ƒ 9.92 |

**Table A1.3: Comparison of alternative one with current situation**

Although the total savings are not very impressive we can see that some savings can be made with the introduction of electronic status messages. These savings are somewhat underestimated because it was assumed that even for electronic execution of the status messages some labor is required to verify the incoming messages. When this assumption is removed the savings will become higher. Most of the time, sending POAs and PODs does not lie on the critical path, therefore the savings in critical time are not very high.

Especially Distribution itself, as chain coordinator can save significant time and money by electronic sending of status messages, because no longer faxes are received and subsequently entered into the central information system by hand.

### A1.2.2 Alternative 2: Preparation of paper work

The following table contains the results for the second alternative, the electronic preparation of various paper work. They are compared with the results from the current situation.

| Order | Total time | | | Critical time | | | Costs | | |
|---|---|---|---|---|---|---|---|---|---|
| | Current | Altern. | Savings | Current | Altern. | Savings | Current | Altern. | Savings |
| 1a | 1605 min. | 1600 min. | 5 min. | 1516 min. | 1508 min. | 8 min. | ƒ 871.45 | ƒ 865.29 | ƒ 6.16 |
| 2b | 263 min. | 258 min. | 5 min. | 197 min. | 189 min. | 8 min. | ƒ 302.17 | ƒ 296.01 | ƒ 6.16 |

**Table A1.4: Results alternative two compared with current situation**

The electronic preparation and sending of the Airwaybill, the proforma invoice and the customs document is a good example of the advantages of parallel execution of certain activities instead of serial. This can be seen by the savings in critical time that exceed the savings in total time. Again, the savings in costs are relatively low, partly because of the assumption that even all electronic messages need labor to verify the messages.

### A1.2.3 Alternative 3: Truck YT in stead of truck VD

Table A1.6 contains the results of the replacement from the trucks from VD by the trucks from YT; the third alternative.

| Order | Costs | | |
|---|---|---|---|
| | Current | Altern. | Savings |
| 1a | ƒ 871.45 | ƒ 892.14 | -/- ƒ 20.69 |
| 1b | ƒ 848.21 | ƒ 878.90 | -/- ƒ 20.69 |
| 2a | ƒ 275.78 | ƒ 294.03 | -/- ƒ 18.25 |
| 2b | ƒ 302.17 | ƒ 320.42 | -/- ƒ 18.25 |
| 3a | ƒ 274.63 | ƒ 291.67 | -/- ƒ 17.04 |

**Table A1.5: Comparison of third alternative with current situation**

In this small example a specific resource is replaced by another. Although this has no effect on total or critical time, the total costs increase because the trucks from the YT department are more expensive than those from VD.

### A1.2.4 Alternative 4: Additional capacity

The final alternative is based on the first example with limited resources. In this example, Customs Handling only possesses one forklift truck and Physical Supply only had one truck (VD) available. Two orders were analyzed, 1 and 2. It was assumed that both airplanes arrived at almost the same time, such that both had to be executed in parallel. This resulted in a total delay of 13 minutes for the second order. In this section it is analyzed if it is possible to solve this problem with a number of additional forklift truck or VD trucks. In table A1.6 below the throughput times of the delayed order 3 are listed, depending on the number of resources available.

| | | **Number of trucks (VD) available** | |
|---|---|---|---|
| | | 1 | 2 |
| **Number of forklift trucks available** | 1 | 198 min. | 198 min. |
| | 2 | 193 min. | 180 min. |

**Table A1.6: Throughput times order 3, depending on resource capacity**

It is remarkable to see that only increasing the number of trucks (VD) from one to two has no effect on the throughput time; it remains 198 minutes. Only when forklift trucks are used does the throughput time decrease with five minutes. When two forklift trucks and two trucks (VD) are deployed, the throughput time decreases to 180 minutes. This was also the critical time when the resources were unlimited, thus by deploying two trucks and two forklift trucks the resource shortage problem is solved.

# APPENDIX 2: DISTRIBUTION CASE - FINAL QUESTIONNAIRE

## 1 Modeling technique and the way of thinking behind MND

1. Does your company use the concept of service elements? If yes, which meaning does it have and what are the consequences for final order fulfillment? If no, to what extent do you think it is possible to translate or express your customer requirements into in service elements?
2. Do you use the concept of production elements in your worn company? That is to say, elements that indicate what products or services each company or business unit can offer. If yes, where do you use this diction what is the purpose? If no, how do you regard this way of modeling?
3. Distribution functions as the TSCC in many orders. To what extent does the true role of Distribution resemble the modeled role (translating customer requirements into service elements, choosing the other participating organizations and translating service elements into production elements)? In other words: how true is the modeling technique for your business sector?
4. Do you think that temporary supply chains can exist in practice? That is to say: temporary coalitions for the duration of one order to increase the flexibility and customer service of the chain. Is such a situation feasible in your chain? Desirable?
5. Does a modular process design exist in your chain/organization? What do you think about this concept?
6. Does, in your opinion, MND offer sufficient support with respect to the generation of alternative scenarios?
7. What do you consider good about the modeling technique? Can you indicate why?
8. What features of MND do you consider most significant: visualization of the process, calculation of costs and throughput times, translation of customer requirements into production, modular process design, planning and scheduling of resources or any other?
9. What do you like less and what do you miss in the method with respect to functionalities and aspects? Are these improvements desirable? Why?
10. Do you have any other remarks about the method and the way of thinking behind MND?

## 2 Erasmus in Chains: MND as DSS

Modular Network Design has been programmed as a Decision Support System. Using this system, called *Erasmus in Chains*, all steps of the approach can be executed, to model the current situation of process handling, to define and assess alternative scenarios and compare the results, on the basis of costs, throughput time and resource usage.

1. What do you think about the user friendliness of *Erasmus in Chains*?
2. How often do you think, will you use the system?
3. Who, within your organization, could be the user of *Erasmus in Chains*? Alternatively, will you hand over usage to external people, like researchers from Erasmus University, because of financial and practical reasons?

4. An option has been added to *Erasmus in Chains* to enable the assessment of limited resources. Is this option necessary for your analyses? Can you work with the current set-up of this option?
5. Do you have any other remarks with respect to Erasmus in Chains?

# 3 Application of MND on own business process

By means of a case study we have applied Modular Network Design on your business processes. A number of orders has been assessed and all accompanying goods and information flows have been analyzed. Furthermore, we have formulated and assessed a number of alternative process scenarios.

1. What was (were) your primary purpose(s) to apply MND?
2. Have these purposes been satisfied?
3. Has the insight into your own processes been increased?
4. To what extent do you consider the collected data reliable enough and therefore, usable?
5. Were other parties involved in the analyses as well? To what extent did you have an interest in insight into their processes or did you already know the other parties' activities beforehand?
6. To what extent do you consider a complete analysis of your chain possible, with respect to the willingness of the other parties to hand over their data, required for this analysis?
7. Which aspect of the analysis was most important for you: development of the DSS, assessment of the current situation or generation and assessment of a number of alternative scenarios?
8. Do you have any other remarks with respect to the application of MND?

# 4 Decision support & possible application areas

MND and *Erasmus in Chains* have been applied on your business processes and within this application a number of alternative process designs have been assessed. MND has specifically been developed to support, in an objective manner, decisions with respect to ICT-enabled Business Network Redesign. The next questions concern possible (other) applications of MND in your organization or supply chain?

1. Do you think MND is suitable to support decision with respect to the redesign of inter-organizational processes and networks? Why or why not?
2. Suppose, the top-management of your organization decides to initiate a change trajectory that includes an investigation and a possible redesign of the entire supply chain. How important do you estimate the role of MND, in percentages, in such a trajectory?
3. To what extent do you think it is possible to implement scenarios, which have been generated and assessed with the method? Where does this depend on?
4. Can you give an indication how decisions with respect to the analyzed alternatives are generally taken in practice, i.e. without an MND analysis?
5. For which type of decisions, with respect to process design in your own organization, do you see possibilities for support with MND and *Erasmus in Chains*?
6. Do you have any other remarks with respect to decision support and possible application areas?

# APPENDIX 3: RESULTS AIR LOGISTICS CASE

## *A3.1 Throughput times current situation*

| NR. | | Total time | Throughput time |
|---|---|---|---|
| **1** | *Carrier* CS GOT | 20 | 0 |
| **2** | Skimlite | 465 | 460 |
| **3** | *Carrier* BU AL | 35 | 0 |
| **4** | *Carrier* BU AC | 1095 | 1060 |
| **5** | Hatchroad | 95 | 85 |
| **6** | Forco | 145 | 145 |
| **7** | USF Holland | 905 | 905 |
| **8** | Oddwire | 40 | 35 |
| **9** | Northwest | 20 | 15 |
| **10** | US Customs | 20 | 20 |
| **11** | ZXV Sweden | 10 | 10 |
| **Totals** | | **2850** | **2735** |

**Table A2.1: Times for order Sweden to US in current situation**

| NR. | | Total time | Throughput time |
|---|---|---|---|
| **1** | *Carrier* CS GOT | 20 | 0 |
| **2** | Skimlite | 960 | 950 |
| **3** | John Realm | 130 | 125 |
| **3** | *Carrier* BU AL | 85 | 50 |
| **4** | Dutch Customs | 35 | 35 |
| **5** | *Carrier* BU AC | 700 | 565 |
| **6** | Hatchroad | 95 | 85 |
| **7** | Forco | 145 | 145 |
| **8** | USF Holland | 905 | 905 |
| **9** | Oddwire | 40 | 35 |
| **10** | Northwest | 20 | 15 |
| **11** | US Customs | 20 | 20 |
| **12** | ZXV Sweden | 5 | 5 |
| **13** | ZXV France | 5 | 5 |
| **Totals** | | **3165** | **2940** |

**Table A2.2: Times for order France to US in current situation**

## *A3.2 Costs current situation*

| NR. | | Current situation (NLG) |
|---|---|---|
| 1 | CS GOT | 29.29 |
| 2 | Skimlite | 391.45 |
| 3 | Air Logistics | 53.65 |
| 4 | BU AC | 1944.73 |
| 5 | Hatchroad | 65.81 |
| 6 | Forco | 92.55 |
| 7 | USF Holland | 756.65 |
| 8 | Oddwire | 39.46 |
| 9 | Northwest | 20.54 |
| 10 | US Customs | 16.60 |
| 11 | ZXV Sweden | 18.00 |
| **Totals** | | **3428.72** |

**Table A2.3: Costs for order from Sweden to US in current situation**

Cost table: Order France - US

| NR. | | Current situation (NLG) |
|---|---|---|
| 1 | CS GOT | 29.29 |
| 2 | Skimlite | 725.70 |
| 3 | John Realm | 112.50 |
| 4 | Air Logistics | 108.38 |
| 5 | Dutch Customs | 29.05 |
| 6 | BU AC | 1555.57 |
| 7 | Hatchroad | 65.81 |
| 8 | Forco | 92.55 |
| 9 | USF Holland | 756.65 |
| 10 | Oddwire | 39.46 |
| 11 | Northwest | 20.54 |
| 12 | US Customs | 16.60 |
| 13 | ZXV Sweden | 9.25 |
| 14 | ZXV France | 9.50 |
| **Totals** | | **3570.85** |

**Table A2.4: Costs for order from France to US in current situation**

# APPENDIX 4: QUESTIONNAIRE FOR ARCHITECTS

## Section A. General information

A1. Name respondent
A2. Name company
A3. Type of company
A4. Is your company part of a bigger concern? Which one?
A5. How many employees and branch offices does your company have?
A6. Could you elaborate on the way your company is organized (organogram)?
A7. What is your position and function within the company?
A8. How did you get involved in the *Gewild Wonen* project in Almere?
A9. Did you ever participate in a similar project, i.e. a project in which the customer can design its own house? If so, which projects? Could you elaborate shortly on each of these projects?

## Section B. Modular design

You submitted a design for *Gewild Wonen*. The following questions concern the realization of this design.
B1. What was the design-assignment you received for this project?
B2. What were the given boundaries for the design?
B3. Did you have enough possibilities to comply with the design assignment within these boundaries? What were the most important bottlenecks?
B4. Could you elaborate on the way you handled the requirement that eventually the customer would have to design his own house?
B5a. Could you please indicate for your design (both exterior as interior design) who eventually has the most influence on the final result? The architect, the buyer or a combination of both?

**Exterior**

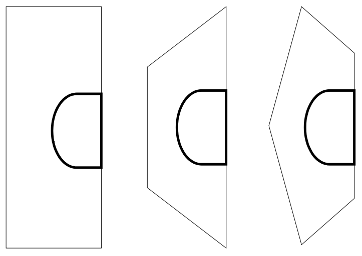
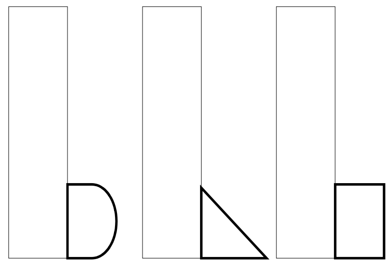
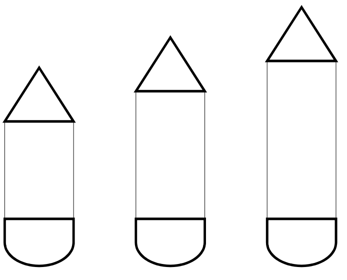
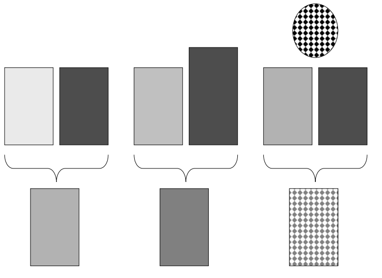
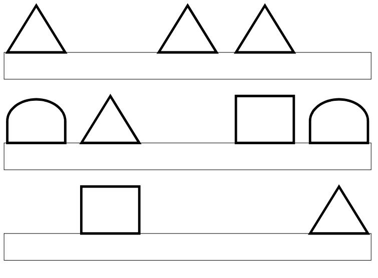
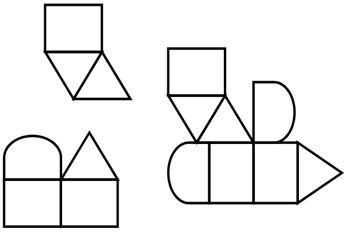
| Architect | | | | Buyer |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

**Interior**

| Architect | | | | Buyer |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

B5b. Is this the most desirable division as well? Why? If not, which division is most desirable alternatively?
B6. What type of problems did you encounter while designing your house?
B7. Modularity plays an important role in this project. Could you indicate at which levels you used modularity in your design?

B8. Table below depicts six types of modularity that may be present in a design. Could you indicate, for each previously mentioned level, what types of modularity you did use?

| | |
|---|---|
| Component-sharing modularity<br><br>The same component is used in different products.<br>Ex. Black & Decker | Component-swapping modularity<br><br>Different components are used in the same product.<br>Ex. Swatch, T-shirts, 'Create-a-Book' |
| Cut-to-fit modularity<br><br>One or more components variable within predetermined limits and requirements.<br>Ex. Bikes, suits, salad buffets | Mix modularity<br><br>Components are mixed such that they change.<br>Ex. Paint, fertilizers, restaurant |
| Bus modularity<br><br>Standard structure where components can be added to.<br>Ex. PC's, cars, textbooks | Sectional modularity<br><br>Configuration of arbitrary number of components on an arbitrary number of ways.<br>Ex. Lego, O-O programming |

We call a design fully modular if a 1:1 mapping exists between functions and physical components and de-coupled physical interfaces between interacting components. This means that a change made to one component does not require a change to other components for a correct functioning of the total product. The opposite of modular is integral.

B9. Did you also use this distinction between components and functions in your design? Could you explain your answer?

B10. Could you please indicate *how* modular your design is in the context of the previous definition?

| Modular | | | | Integral |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

B11. Does your design consist of a (number of) basemodule(s) or a core where upon additional modules or rooms can be assembled? Why did you (not) choose this construction?

B12a. Could you please indicate what percentage of the house is already fixed, because of this construction, and which percentage is free-to-choose by the customer?

B12b. Could you specify these percentages in terms of house functions and/or parts?

B13. How did you accomplish that a certain module can easily be replaced by another module in a later stage?

B14. To what extent did you take the technical aspects of the interfaces (couplings) between the modules into account?

B15. Which changes do you expect for the builders of your (modular) design in comparison with regular building projects?

B16. Does a consumer-oriented building project require different planning and organization than a regular building project? In what matter?

B17. If you compare your design with current 'catalogue houses', where customers also have a certain amount of freedom, what are the biggest differences in your opinion?

B18. Could you indicate a modularity-degree (such as in B10) for these catalogue houses as well?

| Modular | | | | Integral |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

B19. What is, in your opinion the degree of modularity in regular mass-house building?

| Modular | | | | Integral |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

B20. Could you do the same for the degree of freedom for the customer in each of the previously mentioned type of houses? The scale varies from 1 (lot of freedom) to 5 (little freedom).

| Your own *Gewild Wonen* design | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Catalogue houses | | | | |
| 1 | 2 | 3 | 4 | 5 |
| Mass house building | | | | |
| 1 | 2 | 3 | 4 | 5 |

B21. Could you please indicate to what extent you agree with the following statement? 'Arguments for the integral design are often largely technical or performance-based, whereas arguments for the modular tend to be based on business concerns such as cost and time to market.'

| Totally agree | | | | Totally disagree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

B22. Could you please indicate to what extent you agree with the proposed advantages of a modular design?

| | |
|---|---|
| o Bigger variety in supply | o Easy expandability and upgrading |
| o Short delivery time | o Larger design freedom |
| o Lower development costs | o Lower production costs |
| oHigher performance/quality | o ………………………… |

Could you clarify your choices?

B23. Which disadvantages of a modular do you agree with?

| | |
|---|---|
| o Larger design complexity | o Design is easier to copy |
| o Higher probability of 'coupling' errors | o Higher production costs |
| o Higher design costs | o………………………… |
| o Less performance | o………………………… |

Could you again clarify your choices?

B24. Could you specify the demands a design needs to satisfy before it may be called a successful design?

B25a. Which actor, do you think, benefits most from the introduction of modular design and building in the housing industry?

| | | |
|---|---|---|
| o The consumer | o The project developer | o The government |
| o The architect | o The building company | o Others, i.e……………… |

Could you clarify your answer?

B25b. Who will benefit the least?

| | | |
|---|---|---|
| o The consumer | o The project developer | o The government |
| o The architect | o The building company | o Others, i.e……………… |

Could you clarify your answer?

# APPENDIX 5: QUESTIONNAIRE BUILDERS & DEVELOPERS

**Section A. General information**

A1. Name respondent
A2. Name company
A3. Type of company
A4. Is your company part of a bigger concern? Which one?
A5. How many employees and branch offices does your company have?
A6. Could you elaborate on the way your company is organized (organigram)?
A7. What is your position and function within the company?
A8. How did you get involved in the *Gewild Wonen* project in Almere?
A9. Did you ever participate in a similar project, i.e. a project in which the customer can design its own house? If so, which projects? Could you elaborate shortly on each of these projects?

**Section B. Modular building**

***Customer influence***

B1. Does the increased customer influence require a significant change and adjustment for you compared to regular housing projects? What specifically is different than normal?
B2. Did you consider allowing the customer to influence the production process as well, such as certain building techniques or procedures?
B3. What do you think of offering additional services such as financial support, repairs or maintenance?
B4. What do you think are the most important reasons for customers to participate in de *Gewild Wonen* project?

***Relationship between design and building process***

B5. What are the most important adjustments you have to do in the preparation phase as compared to a regular building project?
B6. Did the price and contract phase for *Gewild Wonen* evolve differently than normal?
B7. In what way does consumer-oriented building impact the cooperation with your suppliers? Do these relations become tighter, for instance, or will you reduce the number of suppliers?
B8. In the house design you will realize, modularity has been used repeatedly. What are the most important advantages and disadvantages of the fact that you will now build houses, which are based on a modular system?
B9. Which advantages of mass production can be sustained in this project and which ones disappear because of the increased customization of the houses?
B10. How large is normally the relationship between the architectural design and the building process? In other words which part of the building process if design-dependent?
B11. Do you notice a bigger dependency between design (with standard housing modules) and production (with, e.g., standard production modules)?
B12. Does the influence of the technical capabilities of your company increase or decrease because of the use of a modular design? For instance, will you outsource more of your production?

***Relationship between design and coordination***

B13. Does the architectural design of this project create more or less freedom with regard to the planning of the building project? Could you please clarify your answer?

B14. Did the selection of designing and executing parties take place differently compared to regular projects? What caused these changes?

B15. Do the contacts with other parties evolve differently than normal? Could you please identify in what respect (e.g., type of contracts, work preparation, building team)?

B16. Which aspect of *Gewild Wonen* caused the most problems for you up till now and where do you expect the biggest problems in a later stage?

***Future developments***

B17. Which impact will the increased influence of the customer have on the coordination function in the housing industry?

B18. Will the distinction buyer, designer and executor be less strict in a project such as *Gewild Wonen*.

B19. Does the increased influence of the customer threaten your position in the building network or does this development open up new opportunities for your company?

B20. What are the most important limitations for the mass-customization of houses in the Netherlands?

B21a. Which actor, do you think, benefits most from the introduction of modular design and building in the housing industry?

| | | |
|---|---|---|
| o The consumer | o The project developer | o The government |
| o The architect | o The building company | o Others, i.e……………… |

Could you clarify your answer?

B21b. Who will benefit the least?

| | | |
|---|---|---|
| o The consumer | o The project developer | o The government |
| o The architect | o The building company | o Others, i.e……………… |

Could you clarify your answer?

***Role of Information and Communication Technology***

B22. Which automated information systems does your company use?

B23. What role do these systems play in coordinating and monitoring the designing and executing parties?

B24. Do you envision a bigger role for ICT in projects such as *Gewild Wonen*? What kind of ICT applications do you specifically think of in that respect?

***Success factors***

B25. What extra costs are made when using a modular design? Is the buyer prepared to pay extra for these costs?

B26. Do you think it is possible to deliver the houses in this project in the same time as in a regular housing project? Why (not)?

B27. Could you specify the demands a design needs to satisfy before it may be called a successful design?

# APPENDIX 6: FINAL QUESTIONNAIRE *GEWILD WONEN* ALMERE

**Would you please be so kind to fill out your name and company?**

Name: ……………………………………. Company: …………………………..

## Part 1: Freedom of choice for the customer

| | Totally Disagree | | | Neutral | | | Totally Agree |
|---|---|---|---|---|---|---|---|
| 1. Our buyers had great difficulties making their choices. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 2. We had to guide our buyer intensively during the choice process. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 3. Our buyers had great difficulties with the large amount of freedom offered to them. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 4. Our buyers had a lot of variation in their choices. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 5. Our buyers are mainly starters on the housing market. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 6. Afterwards, it turned out that the majority of the choices offered to the buyers were not selected at all. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 7. Despite the fact that all of our houses have been designed by the same architect, they eventually turned out to be very different. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 8. Most of our buyers selected the biggest variant, i.e. the house with the largest surface and/or volume. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 9. The only responsibility for the architect should be the "house-system", which indicates the basis and limits of the design. The remainder of the design is taken care of by the customer. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 10. Now that all of our buyers have chosen, it turns out that our houses are quite similar to each other. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

## Part 2: Modularity of the house design

| | Totally Disagree | | | Neutral | | | Totally Agree |
|---|---|---|---|---|---|---|---|
| 1. Freedom of choice for the buyer conflicts with the esthetics of the house. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 2. Only when you are very near our houses can you see that all of them have been designed by the same architect. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 3. From a great distance, one can already see that our houses are based on the same basic design. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 4. We do not see the usefulness of expandability of the house in a later phase. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 5. Full customer freedom leads to drearily conventional houses. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 6. The modular measure system, established in the NEN 6000 norm, is very suitable for a project such as *Gewild Wonen*. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 7. Our houses have been designed as such that it is relatively simple to make adjustments to the layout of the house in a later stage. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 8. Our houses have been designed as such that it is relatively simple to expand the house in a later stage. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 9. The freedom of choice for our customer mainly lies on the level of the exterior, i.e. layout, sizes and shape. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 10. The freedom of choice for our customer mainly lies on the level of the interior, i.e. facades, materials and interior. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 11. In our case the customer can select from a number of (standard) components and design his house with these components. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 12. The use of prefab components increases the development complexity of a design. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 13. The use of prefab components is indispensable for building individual houses on a serial basis. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 14. The most difficult part of designing a house that consists of customer-selectable components, is working out the details where these components are attached to each other. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 15. The major challenge of Dwelling Demand is designing a house-system that is as standard and common as possible, but in which 99% of the customers are free enough to make their personal choices. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

## Part 3: Building method

| | Totally Disagree | | | Neutral | | | Totally Agree |
|---|---|---|---|---|---|---|---|
| 1. In the *Gewild Wonen* project we were forced to deviate from our favorite building method. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 2. In this project we used more prefabrication than we normally do. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 3. So-called supporter-infill systems - introduced by Habraken - are very suitable for a project such as *Gewild Wonen*. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 4. The building method we used is in fact not very suitable for a project such as *Gewild Wonen*. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 5. Ideally, hulls should be serially produced, while interior can take place on the building site, fully adapted to the customer's demands. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 6. More investments must be made in the development of flexible building techniques that enable more freedom of choice for the buyer. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 7. For our house design we had to develop one or more new building techniques. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 8. The majority of the consequences of increased customer influence can be solved by so-called *more/less work* solutions. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 9. The chosen building method is the most important factor that eventually determines the freedom of choice for the customer. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 10. Because our house design consists of multiple customer-selectable standard components, we are able to serially produce these components in a cost-efficient manner. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

## Part 4: Business Model

| | Totally Disagree | | | Neutral | | | Totally Agree |
|---|---|---|---|---|---|---|---|
| 1. Cooperation in a building team is the most obvious type of cooperation in a project such as *Gewild Wonen*. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 2. The large complexity of this project has significantly changed the structure and functioning of the building team in comparison with regular building projects. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 3. In the *Gewild Wonen* project we searched for a suitable supplier for each individual house component. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 4. In regular housing projects we use far less suppliers than in the *Gewild Wonen* project. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 5. For a project such as *Gewild Wonen* it is - even more than normally - necessary that the role of order placer and builder are strictly separated. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 6. The responsibilities within the building team were differently distributed compared to regular housing projects. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 7. For this project we specifically looked for new market parties to cooperate with. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 8. Ideally, the buyer himself should also be part of the building team; this will favor the end-result of the project. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 9. In the Netherlands there are not enough suppliers, which are flexible enough for a project such as *Gewild Wonen*. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 10. Builders in the Netherlands are used too much to serial building; | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| therefore projects such as *Gewild Wonen* will most likely never be profitable for them. | | | | | | | |
| 11. For the success of a project such as *Gewild Wonen* it is important that there is one central coordinator or director, who takes take of coordination and control. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 12. Market parties such as building markets and *housing boulevards* must be closer involved in projects such as *Gewild Wonen*. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 13. If consumer-oriented building perseveres, the building industry will probably enter into more temporary, short-term contracts and agreements. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 14. The majority of the relationships and cooperations within building industry may be characterized as informal and personal. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 15. In this project we worked less with our "fixed partners" than we normally do. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

## Part 5: Information and Communication Technology (ICT)

| | Totally Disagree | | | Neutral | | | Totally Agree |
|---|---|---|---|---|---|---|---|
| 1. It would benefit a project such as *Gewild Wonen* if we would could use a (computer) information system that would transfer each customer choice directly to our contractors and suppliers. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 2. We expect that in the future the Internet will play a significant role in the housing market. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 3. Without advanced information systems *Gewild Wonen* will never be applied on a large scale because building companies are not equipped not handle the large amount of (customer and process) information. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 4. The more prefab elements in a design, the more important the role of ICT during the preparation and finishing of the design. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 5. A project such as *Gewild Wonen* could not have taken place 25 years ago, because the information systems that are now available, were non-existent during that time. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 6. Buyers want to know the financial consequences for each of their choices; an automated cost-information system is therefore indispensable. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 7. With respect to cooperation and coordination of the actors in the building process, ICT could play a much more important role than currently and thus improve the efficiency of the building process. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 8. Currently, a lot of mistakes are made during the design and execution phase because actors do not provide each other with the correct information in time. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 9. *Gewild Wonen* is that complex mainly because the amount of information (about costs, choices, planning etc.) that needs to be processed, increases a lot. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 10. Information systems already play an important role during the design and execution phase of most building projects. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 11. Investing in ICT applications is requisite to make projects such as *Gewild Wonen* profitable. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

## Part 6: Success of the project

| | Totally Disagree | | | Neutral | | | Totally Agree |
|---|---|---|---|---|---|---|---|
| 1. *Gewild Wonen* houses are more expensive than regular newly built houses. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 2. Buyers are willing to pay more for more participation, such that the profit margins can stay the same. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 3. House building projects in the Netherlands are not large enough to make serial production on component level profitable. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4. Projects such as *Gewild Wonen* will remain an exception in the future. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 5. The *Gewild Wonen* project has been unprofitable for us. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 6. The Netherlands are too densely populated and built for *Gewild Wonen* on a large scale. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 7. The party that in the future will make the best use of ICT, will play a leading role in consumer-oriented building. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 8. The living environment is for the customer more important than the house itself. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| 9. The total time given to realize this project, has been too short. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

Finally, a question of conscience:

**Which design of the entire *Gewild Wonen* do you consider the most successful, i.e. complies best with the initial project objectives?**

…………………………………………………………………………………………………

**Why?**

…………………………………………………………………………………………………

…………………………………………………………………………………………………

# APPENDIX 7: CUSTOMER INVESTIGATION *GEWILD WONEN*

1. What is your current city of residence?
……………………………………………………

2. What is the composition of your household?
…… adults and …… children.

3. What is your highest education?

o LBO o MAVO o HAVO o VWO
o MBO o HBO o WO o Other

4. In what kind of house do you live at the moment? Is this an owner-occupied or a rental house?

o Detached house o Row house | o Rental house
o Duplex o Apartment / Flat | o Owner-occupied house
o Other, i.e. ………………………………………………

5. What is for you the most important reason to participate in Gewild Wonen?

o I (we) want more influence on the design of my/own house.
o I want to be able to expand my house in the future without much trouble.
o The house supply elsewhere does not comply with my home situation and demands.
o I want to live in Almere
o Other reason, i.e.. ……………………………………………………………….

6. Could you please indicate to what extent the statements below describe your situation?

| | Completely disagree | | | Neutral | | | Completely agree |
|---|---|---|---|---|---|---|---|
| I know a lot about architecture and house design | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I like do-it-yourself work | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I like to watch housing programs on TV. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I like to participate in and decide about the design of my house. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I am a relative newcomer to the housing market. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I already have more experience with self-building a house. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| Designing my house was more difficult than I expected. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

7. For which subproject of Gewild Wonen did you sign up?

o High-rise o Low-rise
Architect: ……………………………………. Developer:…………………………………

8. Could you please why you did sign up for this sub-project in particular?

o The specific location of the houses.
o The amount of influence I could have on the design of the house.
o Because it concerns a rental house in this project..
o The price of the house.
o The total image of the house.
o The architect of the house.
o Other reason, i.e. ………………………………………………………………

The subsequent questions concern your <u>expectations</u> and <u>experiences</u> with respect to the project you signed up for. Could you indicate for each of the statements to what extent you agree with each of them by circling your answer?

9. In a project such as Gewild Wonen I think it is <u>important</u> that…

| | Completely disagree | | | Neutral | | | Completely agree |
|---|---|---|---|---|---|---|---|
| The information brochures offer clear information and are complete. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I am guided with (visual) aids, such as a model or a CD-Rom, during the design process. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| Promises with respect to freedom of choice, delivery and prices are met by the seller. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| The seller is always willing to help me. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| The seller quickly answers my questions. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I am guided by someone with experience during the choice and design process. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I receive individual attention from the seller. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| The seller understands my requirements. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I may influence the exterior of the house (size, shape and appearance). | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I may influence the interior of the house (spatial design, location of facilities and interior-specialties). | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I may influence the finishing of the house (colors, material and accessories). | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I may not only influence the house design but my living environment as well. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

10. My <u>experiences</u> during the Gewild Wonen project until now are that…

| | Completely disagree | | | Neutral | | | Completely agree |
|---|---|---|---|---|---|---|---|
| The information brochures offer clear information and are complete. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I am guided with (visual) aids, such as a model or a CD-Rom, during the design process. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| Promises with respect to freedom of choice, delivery and prices are met by the seller. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| The seller is always willing to help me. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| The seller quickly answers my questions. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I am guided by someone with experience during the choice and design process. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I receive individual attention from the seller. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| The seller understands my requirements. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I may influence the exterior of the house (size, shape and appearance). | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I may influence the interior of the house (spatial design, location of facilities and interior-specialties). | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I may influence the finishing of the house (colors, material and accessories). | -3 | -2 | -1 | 0 | 1 | 2 | 3 |
| I may not only influence the house design but my living environment as well. | -3 | -2 | -1 | 0 | 1 | 2 | 3 |

By means of the following questions we would like to elaborate further on your personal experiences during the design process the past couple of months.

11. Do you have the feeling that you had enough possibilities to design your optimal house?
12. Were you adequately guided during the process? What was particularly good and bad?
13. What did you think of the contributions of the architect, the developer, the broker, the builder?
14. Do you have any other remarks with respect to the Gewild Wonen project?

# APPENDIX 8: SURVEY ON BUSINESS MODULARITY[36]

Dear Participant,

Why is customization of products so successful, especially on the World Wide Web?

Most likely, this is a very tempting business issue for you. I found your organization and the customizable products you offer on the Internet via digichoice.com. Currently, I am working on a Ph.D. thesis about Mass-Customization on the Web at Erasmus University Rotterdam in the Netherlands.

It gives me great pleasure to invite you to cooperate in this research by completing the attached questionnaire. It will take you only **15 MINUTES**. Most questions focus on marketing or business operation issues.

I realize that you receive invitations to fill in questionnaires almost on a weekly basis, so I would like to give you four compelling reasons why you should seriously consider my invitation to participate:

1. You will receive an in-depth summary of the research **FOR FREE** based on the survey results explaining why Mass-Customization on the Web is successful and how you can achieve success.
2. The research is truly independent undertaken at one of the top business schools in Europe. Therefore, you will be reading a high quality publication.
3. I will by no means use your information for any other purpose. Your information will be treated confidential and with full anonymity.
4. Most important of all, you will enjoy it. Filling in the questionnaire and reading the results will have an instant advantage for you.

Please accept my invitation and after filling in the questionnaire use the **Send button** below. Thank you very much for your cooperation.

Yours sincerely,

Matthijs Wolters
Erasmus University Rotterdam / Rotterdam School of Management

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[36] The survey is not displayed in its original layout.

**Question 1:**
Which customizable product or service do you offer? (In the case of multiple products, please choose the best selling customizable product/service your organization offers)
………………………………
[From this point on, this product or service will be indicated as the 'product' in this survey.]

**Question 2:**
How many people are employed in your organization?
o 1-9 o 10-49 o 50-99 o 100-499 o 500-999 o 1000+

**Question 3:**
How many people are employed in your business unit?
o 1-9 o 10-49 o 50-99 o 100+
[From this point on, this business unit will be addressed as 'we' or '(y)our'.]

**Question 4:**
How many people work under your supervision?
o 0-4 o 5-9 o 10-24 o 25-99 o 100+

**Question 5:**
Customers who buy our product(s) are mainly:
o Private persons o Businesses
[From this point on, these will be addressed as the 'customer'.]

**Question 6:**
Please indicate the degree of freedom your customer has in customizing your product on the scale below:
No freedom o o o o o o o Full freedom

**Question 7:**
How many different product configurations can your customer(s) choose from?
o 0-9 o 10-49 o 50-99 o 100-999 o 1000+

**Question 8:**
Using the rating scale shown below, please choose one number for each set of factors listed. Choose the number which best reflects your opinion of where your product falls on each scale.

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| A | Standardized product | o | o | o | o | o | Differentiated product |
| B | Technically simple | o | o | o | o | o | Technically complex |
| C | Easy to use / install | o | o | o | o | o | Specialized installation / use |
| D | No after sales service | o | o | o | o | o | Technical after sales service |
| E | No configuration support required | o | o | o | o | o | Extensive configuration support required |

**Question 9:**
Using the rating scale shown below, please choose one number for each set of factors listed. Choose the number which best reflects your opinion of where your manufacturing processes fall on each scale.

| | | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|
| A | We take care of all product manufacturing ourselves | o | o | o | o | o | Other parties take care of all product manufacturing |
| B | Production units are located in one area | o | o | o | o | o | Production units are geographically dispersed |
| C | Low degree of specialization within production units | o | o | o | o | o | High degree of specialization within production units |
| D | Production and assembly are combined | o | o | o | o | o | Production and assembly are separated |
| E | Large dependency between production units | o | o | o | o | o | Large autonomy for production units |
| F | Continuous production | o | o | o | o | o | Step-wise production |

**Question 10:**
Please indicate to what extent you agree with the statements below:
*Customer Characteristics:*

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| Our customers are quite sure about what they require in our product (CI1) | o | o | o | o | o |
| Our customers are willing to participate in the customization process (CI2) | o | o | o | o | o |
| We have a very diverse customer base (CI3) | o | o | o | o | o |
| It is easy for our customers to customize our product (CI4) | o | o | o | o | o |
| Our customers increasingly want more influence on the design of our product (CI5) | o | o | o | o | o |
| Our customers have very different preferences with respect to the features of our product (CI6) | o | o | o | o | o |

*Product Modularity:*

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| Our product can easily be upgraded or updated by our customers after they have purchased the product | o | o | o | o | o |
| The components we buy for our product easily fit together even if they are supplied by different firms | o | o | o | o | o |
| Our product consists of several distinct components, each with a clearly specified function | o | o | o | o | o |
| Our product has extensive "plug-and-play" functionality | o | o | o | o | o |
| You can split our product into many different parts after which you can easily put them back together without losing functionality | o | o | o | o | o |

| | | | | | |
|---|---|---|---|---|---|
| You can think of our product as a construction box consisting of various building blocks | o | o | o | o | o |

*Supply Chain Modularity:*

| | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|---|
| We contact our suppliers mainly for issues relating to specific customer requests | o | o | o | o | o |
| We mostly engage in temporary, short-term contracts with our suppliers | o | o | o | o | o |
| We use multiple, interchangeable suppliers for our key components | o | o | o | o | o |
| We use the same trade rules and procedures for all our suppliers | o | o | o | o | o |
| We are completely free to buy from any supplier that we want | o | o | o | o | o |
| Our product components are very much "off-the-shelf" items which are supplied by many different firms | o | o | o | o | o |

**Question 11:**
Please indicate how your customers are supported in the process of designing and selecting their product (more than one answer allowed):
o Personal guidance and advice (physical)
o Price quotes
o CD-Rom
o Virtual Reality applications
o Scale model
o Web-based support tools (e.g., electronic shop assistant)
o Collaborative filtering (personal advice based on other people's purchases)
o Standard illustrative configurations

**Question 12:**
Please indicate the percentage of customers who bought your product on-line (via the World Wide Web) and the percentage of total sales that were completed on-line in the past 12 months:
[ ] percent on-line customers and [ ] percent on-line sales

**Question 13:**
Please indicate the percentage of suppliers with whom you have an Electronic Data Interchange (EDI) connection:
[ ] percent

**Question 14:**
Please indicate the percentage of suppliers with whom you communicate via E-mail:
[ ] percent

**Question 15:**
Which one of the following best describes the role of Information Technology (IT) in your organization? Please check only one:

o Traditional Role: IT supports operations and facilitates decision support and administrative functions, but is not related to our customization strategy.

o Evolving Role: IT supports the customization strategy. Information System (IS) groups actively support the organization's strategies but are not an integral part of the strategy formulation process.

o Integral Role: IT is integral to the customization strategy. Highly proactive orientation to IT, where IS and executive management work together to change competitive patterns in the industry.

**Question 16:**
Could you please give an estimate of the life cycle of your product:
[ ] years

**Question 17:**
What percentage of your company's 1999's total revenue came from new product introductions?
[ ] percent of last year's revenues came from "new" products

**Question 18a:**
Did the prices of input materials increase or decrease over the past five years?

o The prices of input materials increased
o The prices of input materials remained the same
o The prices of input materials decreased

**Question 18b:**
By what percentage on average?
[ ] percent per year

**Question 19a:**
Below you find six pre-defined business objectives related to the (mass-)customization of products. Could you indicate which of these objectives you wanted to achieve when you decided to offer customizable products to your customers? You may also formulate additional business objectives and select them.

o 1 Cost minimization
o 2 Increased customer intimacy
o 3 High product innovation rate
o 4 Competitive product pricing
o 5 Increase product variety
o 6 Minimize product development time
o 7 [ ]
o 8 [ ]

**Question 19b:**
Can you allocate 100 percent points to the objectives you selected according to their relative importance?

1 Cost minimization …. points
2 Increased customer intimacy …. points
3 High product innovation rate …. points
4 Competitive product pricing …. points
5 Increase product variety …. points
6 Minimize product development time …. points
o 7 [ ] …. points
o 8 [ ] …. points

**Question 19c:**
Finally, can you please indicate for the above objectives to what extent you have achieved them?

| | | | | | |
|---|---|---|---|---|---|
| 1 Cost minimization | o 0% | o 25% | o 50% | o 75% | o 100% |
| 2 Increased customer intimacy | o 0% | o 25% | o 50% | o 75% | o 100% |
| 3 High product innovation rate | o 0% | o 25% | o 50% | o 75% | o 100% |
| 4 Competitive product pricing | o 0% | o 25% | o 50% | o 75% | o 100% |
| 5 Increase product variety | o 0% | o 25% | o 50% | o 75% | o 100% |
| 6 Minimize product development time | o 0% | o 25% | o 50% | o 75% | o 100% |
| 7 [ ] | o 0% | o 25% | o 50% | o 75% | o 100% |
| 8 [ ] | o 0% | o 25% | o 50% | o 75% | o 100% |

# SAMENVATTING

Dit proefschrift heeft als Nederlandse titel ‘Modulariteitszaken en Zakelijke Modulariteit’ meegekregen, als vertaling van het Engelse ‘The Business of Modularity and the Modularity of Business’. Deze vertaling illustreert fraai dat de Nederlandse taal waarschijnlijk minder modulair is dan de Engelse. In het Engels is het makkelijker om woorden, de modules, om te wisselen of te vervangen zonder dat de woorden hoeven te worden veranderd terwijl het wel een goede zin blijft. De Nederlandse grammatica, de zinsarchitectuur, leent zich minder goed voor een dergelijke flexibiliteit. Hiermee zijn we direct bij de kern van dit proefschrift beland. In dit proefschrift is geprobeerd om enerzijds de betekenis van het begrip modulariteit verder uit te diepen (modulariteitszaken) en anderzijds om de bruikbaarheid van modulariteit in netwerken van organisaties (zakelijke modulariteit) te onderzoeken.

Zakelijke modulariteit op zichzelf bestaat al enkele decennia. Starr was in 1965 één van de eersten die aandacht schonk aan modulaire productie. Sinds enkele jaren is de aandacht voor modulariteit echter aanzienlijk toegenomen door een aantal ontwikkelingen in zowel de wetenschap als het bedrijfsleven. De belangrijkste daarvan is de opkomst van massa-individualisering (*mass-customization*). Massa-individualisering kan het beste worden omschreven als ‘het gebruik van flexibele processen en organisatiestructuren om gevarieerde en geïndividualiseerde producten en diensten voort te brengen tegen dezelfde prijs als massa-geproduceerde alternatieven’ (Hart 1996). Massa-individualisering biedt een oplossing voor de eeuwigdurende worsteling tussen duur maatwerk en goedkope, serieel vervaardigde producten. Autofabrikant Ford koos in de jaren ’20 en ’30 heel bewust voor alleen maar zwarte T-Fords om de auto zodoende voor iedereen betaalbaar te houden. De kleermaker op de hoek koos de tegenovergestelde strategie en mat zijn klanten een perfect passend kostuum aan. Die hadden voor dit pak echter, naast een behoorlijke dosis geduld, wel een goed gevulde beurs nodig.

Sinds het gebruik van Informatie- een Communicatietechnologie (ICT) lijkt het dat deze paradox opgeheven kan worden. Autofabrikanten hebben hun productielijnen zodanig geautomatiseerd dat steeds een andere, unieke auto van de band rolt. De kleermaker ondertussen heeft ook niet stilgezeten. Het bekendste voorbeeld hiervan is het Personal Pair van Levi’s. In plaats van dat je allerlei verschillende spijkerbroeken moet passen, worden nu je maten opgenomen door de verkoper en vervolgens ingevoerd in de computer. Binnen enkele minuten maakt de computer uit bijna 15.000 verschillende modellen en varianten de optimale keuze. Deze perfect passende spijkerbroek wordt vervolgens binnen enkele weken thuisbezorgd en dat voor slechts een paar tientjes meer.

Daarnaast heeft het Internet de ontwikkelingen op het gebied van massa-individualisering een extra impuls gegeven. Meer en meer bedrijven, in uiteenlopende branches en industrieën, gebruiken de mogelijkheden van dit medium om betaalbaar maatwerk te leveren. Zo is het bijvoorbeeld mogelijk om via www.barbie.com je eigen barbiepop samen te stellen. Computerfabrikanten, zoals het Amerikaanse Dell, zijn eigenlijk pas succesvol geworden sinds ze hun klanten zelf via het World Wide Web hun nieuwe PC laten samenstellen. En op de website van juwelier Desiree kunnen aanstaande bruidsparen zelf hun trouwringen ontwerpen.

Het gebruik van modulariteit in het ontwerp van zowel producten, bedrijfsprocessen en organisatiestructuren zou deze flexibiliteit en betaalbare individualisering heel goed mogelijk kunnen maken. De vraag is echter wat er precies onder modulariteit wordt verstaan en hoe en wanneer het vervolgens kan worden toegepast. Op welke wijze kunnen bedrijven hun producten, processen en structuren modulariseren en wat levert het ze op? Hoe kan ICT worden ingezet om kosten te besparen en tegelijkertijd toch de consument op maat te bedienen? Veel organisaties vragen zich af hoe men de traditionele, rigide structuren kan reorganiseren tot flexibele, klantgerichte bedrijfsmodellen. Men zoekt naar methoden en technieken die hun daarbij kunnen ondersteunen. Eén van deze methoden is *Modular Network Design* (MND), bedacht en ontwikkeld door Martijn Hoogeweegen, die daarop in 1997 promoveerde. Hij ontwikkelde MND in eerste instantie om de inzet van Electronic Data Interchange in waardeketens te kunnen evalueren. Gedurende zijn onderzoek rees bij Hoogeweegen echter het vermoeden dat de methode voor meer doeleinden inzetbaar zou kunnen zijn. In dit proefschrift is dit laatste vermoeden als startpunt genomen voor verder onderzoek naar het gebruik van modulariteit, omdat MND op innovatieve wijze de hiervoor beschreven ontwikkelingen combineert in één model. Wij waren geïnteresseerd in welke mate MND daadwerkelijk een bijdrage kon leveren aan het ontwerp van geïndividualiseerde en kosten-efficiënte bedrijfsnetwerken, d.w.z. bedrijfsnetwerken die in staat zijn om betaalbaar maatwerk te leveren. De initiële onderzoeksvraag luidde dan ook als volgt:

**Hoe en in welke mate ondersteunt Modular Network Design het ontwerp van geïndividualiseerde kosten-efficiënte bedrijfsnetwerken?**

MND bestaat in feite uit twee gedeelten: een empirisch descriptief en een conceptueel prescriptief deel (Bosman 1986). Het empirisch descriptieve deel is een verzameling analytische methoden, zoals *Activity Based Costing* en kritieke pad analyse, aangevuld met de mogelijkheid om bedrijfsprocessen te visualiseren en zodoende inzichtelijk te maken. Ook de mate van flexibiliteit en klantgerichtheid van een bedrijfsnetwerk kan in principe met MND worden vastgesteld. Het conceptueel prescriptieve deel van MND is daarnaast een model dat organisaties voorschrijft *hoe* men bedrijfsprocessen en –structuren zou moeten ontwerpen om daadwerkelijk betaalbaar maatwerk te leveren. Kernbegrippen in dit deel van MND zijn: tijdelijke samenwerkingsverbanden van organisaties (dynamische netwerken), modulair ontwerp, een tijdelijke ketencoördinator en een directe relatie tussen klantenwensen enerzijds en de voortbrengingsprocessen anderzijds.

Om de validiteit en toegevoegde waarde van MND vast te stellen was het noodzakelijk om te onderzoeken:

1. Of de analytische en visualisatie methoden van het empirisch descriptieve deel van MND inderdaad de juiste methoden zijn om te bepalen in hoeverre bedrijfsnetwerken betaalbaar maatwerk kunnen leveren en of deze methoden correct zijn geoperationaliseerd in de methode.

2. In hoeverre de ontwerpconcepten van het conceptueel prescriptieve deel van MND (zoals modulair ontwerp en tijdelijke samenwerkingsverbanden van organisaties) vertaald kunnen worden in praktisch bruikbare richtlijnen of methoden.

Dit onderzoek is uitgevoerd in de luchtvrachtsector. Luchtvrachtvervoerders spelen een cruciale rol in het verbeteren van de klantgerichtheid en efficiency van hun klanten, de verladers. De waardeketens van deze verladers dienen zodanig te worden ingericht dat op tijd kan worden voldaan aan de meest uiteenlopende klantenwensen. Snel en betrouwbaar transport speelt daarin een essentiële rol. Mede daarom wordt er door deze verladers grote waarde gehecht aan complete dienstverlening op maat; men gaat op zoek naar leveranciers van wereldwijde *One Stop Shopping* logistieke diensten, die het hele vervoerstraject van deur tot deur voor hun rekening kunnen nemen. Het bedrijf waar het onderzoek is uitgevoerd, is een belangrijke speler in deze markt en het wilde met MND meer inzicht krijgen in zijn eigen structuur en prestaties.

Het onderzoek naar de validiteit van MND heeft een aantal belangrijke bevindingen opgeleverd. MND kan goed worden gebruikt voor kleine, incrementele herontwerp beslissingen, mits de doelstellingen vooraf goed zijn geformuleerd en de bedrijfsprocessen al redelijk gestructureerd verlopen. MND ondersteunt daarnaast bedrijven op een conceptuele manier door een nieuw perspectief te bieden op het inrichten van bedrijfsprocessen. Het kan managers bijvoorbeeld ondersteunen bij het ontdekken van mogelijkheden om ICT in te zetten gericht op het bedienen van de klant in plaats van op kostenbesparingen alleen. Dit perspectief kenmerkt zich vooral door de directe relatie die wordt gelegd tussen klantenwensen enerzijds (service elementen) en het achterliggende voortbrengingsproces anderzijds (productie elementen) en door de nadruk te leggen op modulair organiseren. Dit is echter tegelijkertijd de zwakte van MND. De combinatie van twee perspectieven (empirisch descriptief en conceptueel prescriptief) in één model zorgt er namelijk voor dat de methode vaak hinkt op twee gedachten. Aan de ene kant is het een gedetailleerde proces-analyse methode, aan de andere kant worden voorschrijvende uitspraken gedaan over strategische ontwerpbeslissingen als massa-individualisering, dynamisch netwerken en modulair organiseren. Deze combinatie leidt helaas tot een ongewenste mengvorm van overdetaillering en veralgemenisering van het model; het zou beter zijn om een expliciete keuze te maken voor één van beide perspectieven.

Hiermee was de eerste onderzoeksvraag beantwoord. De laatste constatering rechtvaardigde het besluit om het vervolg van het onderzoek te richten op het conceptueel prescriptieve deel van MND, in het bijzonder het modulair organiseren. Modulariteit was weliswaar een onderdeel van MND, maar operationalisering en vertaling in praktische richtlijnen bleek erg lastig en onvoldoende specifiek. Dit leidde tot een nieuwe onderzoeksvraag:

**Hoe kan modulariteit de effectiviteit van netwerken van organisaties verbeteren?**

Op basis van de hiervoor beschreven bevindingen rond de toepassing van MND en een uitgebreid literatuuronderzoek is eerst geprobeerd om een heldere definitie van het begrip modulariteit te formuleren.

Dit leverde vijf belangrijke kenmerken op:

- Duidelijk te onderscheiden componenten.
- Losse koppeling tussen de componenten, strakke koppeling binnen de componenten.
- Heldere, één-op-één relatie tussen de componenten en de functies die deze componenten vervullen.
- Gestandaardiseerde, duidelijk gespecificeerde interfaces die de componenten met elkaar verbinden.
- Grote zelfwerkzaamheid van componenten; coördinatie ingebed in modulaire architectuur.

Bovenstaande kenmerken tezamen definiëren de modulariteit van een systeem. De volgende stap was de ontwikkeling van een theoretisch raamwerk dat inzicht biedt in hoe en onder welke omstandigheden netwerken van organisaties het best modulariteit kunnen toepassen en welke andere factoren van invloed zijn op de relatie tussen modulariteit en effectiviteit. Met effectiviteit wordt hier verwezen naar de doelmatigheid en het succes van deze netwerken in het algemeen, maar in het bijzonder massa-individualisering.

De centrale propositie in het theoretische raamwerk is vervolgens dat het gebruik van modulariteit voor massa-individualisering het meest succesvol is als dat simultaan gebeurt in de drie dimensies product, proces en keten onder de voorwaarde dat de eindconsument kàn en wìl participeren in het ontwerp van deze dimensies. Met simultaan wordt hier bedoeld dat de mate van modulariteit van deze dimensies in balans dient te zijn. Een hoge product modulariteit dient vergezeld te gaan van een hoge modulariteit van de bedrijfsprocessen en de ketenstructuur. De mate van modulariteit wordt voor een belangrijk deel bepaald door de wens van de consument om te participeren in het ontwerpproces van de drie dimensies. Hoe groter deze wens, hoe wenselijker modulariteit.

Om de geldigheid van deze en aanverwante proposities uit het raamwerk te onderzoeken is allereerst het raamwerk verder ontwikkeld en geoperationaliseerd door middel van een gevalstudie in de Nederlandse bouwwereld. In het bijzonder ging de aandacht uit naar een experimenteel bouwproject in Almere, genaamd Gewild Wonen. In dit project probeerden 15 projectontwikkelaars en wooncorporaties gezamenlijk ruim 550 nieuwbouwwoningen te realiseren waar de koper zelf invloed mocht uitoefenen op het ontwerp van het huis. Dit project was een mooi voorbeeld van massa-individualisering. Daarnaast bood het ons een uitgelezen mogelijkheid om de geldigheid van het theoretische raamwerk te onderzoeken en te analyseren hoe en in welke mate de betrokken organisaties modulariteit toepasten.

Veel van de ontwerpen in het Gewild Wonen-project maakten op de een of andere manier gebruik van modulariteit. Vaak was er sprake van een basismodule, die alle noodzakelijke voorzieningen bevatte, zoals het leidingwerk, het sanitair en het trapgat. Om de basismodule heen kon de bewoner zelf zijn gang gaan door nu, of in een later stadium als het huis al bewoond was, additionele modules te selecteren. Het ging hier dus om modules op het niveau van de ruwbouw van het huis: de omvang en de uiterlijke vormgeving van het huis. Het gebruik van een basismodule zorgde er ook voor dat er toch seriematigheid in het ontwerp bleef. Het valt echter te bezien of er in de huizenbouw door het gebruik van modulariteit schaalvoordelen op module-niveau kunnen worden behaald. Het aantal te produceren modules zou daarvoor wel eens te laag kunnen zijn en de levensduur van een huis te lang. Men zag bovendien weinig in het idee van standaard keuken- of slaapkamermodules. Woonmodules hadden vooral (extra) volume als functie; de bewoner bepaalde vervolgens zelf wel waar deze ruimte voor werd gebruikt.

Door de grotere modulariteit in de huisontwerpen werden de bouwers bijna automatisch gedwongen om ook de bouwmethodieken modulairder te maken. Dit betekende dat de methoden die huizen 'uit-één-stuk' voortbrengen, zoals gietbouw, veelal vervangen werden door flexibelere methoden als houtskeletbouw. Als we daarnaast kijken in hoeverre men is afgeweken van de reguliere ketenstructuur en of deze structuur modulairder is geworden (net als de huizen zelf), is te zien dat men vrij weinig wijzigde ten aanzien van deze aspecten. Men ging niet over op meer leveranciers, de rollen van opdrachtgever en bouwer werden niet strikter gescheiden en ook bleef men met zijn vaste partners werken. Wel kon worden geconstateerd dat een simultaan ontwerp van de drie dimensies product, proces en keten over het algemeen goed werkte, onder de voorwaarde dat rekening werd gehouden met de wensen van de koper. Hiermee wordt bedoeld dat de ontwerpende en uitvoerende partijen de juiste balans probeerden te vinden in koperseisen, ontwerp, bouwmethode en organisatiestructuur. Als de kopers niet veeleisend waren, omdat ze bijvoorbeeld nieuwkomers waren op de woningmarkt, dan was het aanbieden van enkele huisvarianten voor dit type koper al 'wild' genoeg. Werd de lat hoger gelegd, enerzijds gedwongen door veeleisende kopers, anderzijds door de uitvoerders en ontwerpers zelf, dan eiste dit van alle betrokken partijen meer moeite en aanpassingen. Niet alleen moesten kopers meer kennis van zaken hebben en weten wat ze wilden, hetzelfde gold voor de bouwpartijen. Het huisontwerp moest meer keuzevrijheid bieden, de bouwmethodiek flexibeler zijn en ook het organisatiemodel moest worden aangepast. Modulariteit van zowel huisontwerp, bouwmethode en organisatiemodel bood dan zeker mogelijkheden, maar was over het algemeen moeilijker te realiseren dan een meer integraal ontwerp. Inzetten van ICT was in dit geval essentieel en de dialoog met de consument diende intensief en frequent te zijn.

Aansluitend op deze gevalstudie is geprobeerd om de bevindingen uit de bouwwereld te generaliseren naar andere industrieën door middel van een enquête onder circa 200 internationale organisaties die zich richten op (massa-)individualisering van hun producten en diensten. De enquête leidde tot meer inzicht in de geldigheid en bruikbaarheid van het theoretische raamwerk.

De voornaamste bevinding was dat sommige industrieën (zoals de bouw, de uitgeversbranche en de sportartikelen sector) een hoge mate van productmodulariteit inderdaad koppelen aan een hoge proces- en ketenmodulariteit. In andere industrieën daarentegen (zoals meubilair en muziekinstrumenten) werd juist een lage modulariteitsgraad in deze drie dimensies aangetroffen. Daarnaast bleek dat eerstgenoemde industrieën vooral excelleren in een combinatie van efficiëntie en klantgerichtheid, massa-individualisering dus, terwijl laatstgenoemden uitblonken in innovatie en productontwikkeling. Dit bevestigt onze centrale propositie dat een simultaan ontwerp in de drie dimensies (product, proces en keten) inderdaad zinvol is en dat een modulair ontwerp van deze dimensies essentieel is voor succesvolle massa-individualisering. Ten slotte bleek dat een modulaire ketenstructuur gebaat is bij ICT-toepassingen met een lage relatie-specificiteit en lage *switching costs* die de autonomie van en de losse verbanden tussen de verschillende modules handhaven.

In het laatste deel van dit proefschrift is een aantal mogelijke richtingen voor vervolgonderzoek naar zakelijke modulariteit gepresenteerd. Allereerst verdient het aanbeveling om verder onderzoek te doen naar de ontwikkeling van een methode die, voortbouwend op *Modular Network Design* en het theoretische raamwerk gericht op zakelijke modulariteit, in staat is om de effecten van massa-individualisering te modelleren en te analyseren. In het Gewild Wonen-project kwam bijvoorbeeld duidelijk naar voren dat er bij bouwers en ontwikkelaars behoefte bestaat aan een reële inschatting van de kosten en baten van een massa-individualiseringsstrategie.

Dit brengt ons automatisch bij de tweede suggestie voor verder onderzoek: massa-individualisering in de bouw. De belangrijkste les die uit het Gewild Wonen-project kon worden geleerd was ‘dat het allemaal nog niet meeviel’. Het initiatief van de gemeente Almere was bijzonder en gedurfd. De partijen die meewerkten aan Gewild Wonen wisten voor welke uitdaging ze stonden en dat het een project zou worden met veel onzekerheden en hoge tijdsdruk. Het bleek echter dat het realiseren van een project als Gewild Wonen geen sinecure was voor bouwend Nederland. Huisontwerpen waren soms te ambitieus, de toegenomen kopersinspraak was lastig te *managen*, de informatieverstrekking richting de kopers liet te wensen over, het Bouwbesluit was een lastig te nemen obstakel en de tijd om het project succesvol af te ronden was voor menigeen te kort. Dat dergelijke problemen zich zouden voordoen was niet geheel verrassend; het betrof hier immers een experiment waaruit lessen kunnen worden getrokken voor de toekomst. De bouwwereld probeert intussen om het Gewild Wonen project elders in Nederland vervolg te geven en gebruik te maken van de opgedane ervaringen in Almere. Onderzoek naar organisatorische oplossingen, de inzet van ICT en het betrekken van de consument in het bouwproces is daarbij onontbeerlijk.

Tenslotte is het zinvol om het onderzoek onder diverse massa-individualiserende organisaties verder voort te zetten. De enquête leverde enkele verrassende resultaten op die soms moeilijk theoretisch te verklaren waren. Waarom, bijvoorbeeld, is de bouw ‘modulairder’ dan de industrieën voor muziekinstrumenten of meubilair? Vermoedelijk heeft dat te maken met de omvang, de fragmentatie, de rol van ICT in het ontwerpproces en de beschikbaarheid van standaarden in de industrieën, maar deze vermoedens zijn vooralsnog niet theoretisch onderbouwd. Vervolgonderzoek gericht op de vergelijking van de verschillende industrieën op deze en andere (modulariteits-)criteria is aan te bevelen.

# CURRICULUM VITAE

Matthijs Wolters was born on June 4th 1972 in Dronten, the Netherlands. He studied Econometrics at the University of Groningen, with a specialization in Operations Research and Statistics. During his study he was involved in a number of research investigations, varying from forecasting the outcome of tennis matches to a viewers inquiry for a popular-scientific television program. He graduated in 1996 on a thesis that dealt with the development and testing of algorithms and heuristics for efficient orderpicking in warehouses.

Since October 1996 he has been working at the Erasmus University Rotterdam as a Ph.D. candidate on modularity, mass-customization, dynamic networking and ICT. His research was published in several newspapers, books and journals and he presented his work at international conferences. He also supervised a number of graduation students with their master's project. In 1998 he organized an international conference 'Electronic Commerce: Crossing Boundaries'. Recently, he has started his own company Ludens Research and Consultancy in which he continues his work on customer-oriented organizing and modularity.

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## The Business of Modularity and the Modularity of Business

This thesis deals with the concept of modularity, which is used in many different fields of research and applications. The objective of this dissertation is to investigate how and to what extent business networks can use modularity to become more customer-responsive and flexible. For this purpose, a theoretical framework on modularity has been developed, which focuses on three dimensions of doing business: designing products, business processes and supply chains. The central proposition is that a concurrent, modular design in these three dimensions increases the performance of inter-organizational business networks in general and a mass-customization strategy in particular. This proposition was validated in a number of empirical settings. First, the applicability of a business modeling approach, called Modular Network Design, was validated in the air cargo industry. Second, it was investigated how the Dutch building industry applies modularity in order to mass-customize newly built houses. Third, a survey was held among numerous customizing organizations, dispersed all over the world, which led to more understanding about the relationship between business modularity and organizational performance.

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