Magnus Hellström

Business Concepts Based on Modularity

A Clinical Inquiry into the Business of Delivering Projects

Magnus Hellström
b. 1975
M.Sc (Tech.) 2002, Åbo Akademi University
Works at PBI - Research Institute for Project Based Industry

Cover and layout: Tove Ahlbäck

Cover picture: Virpi Haavisto
The picture is from the booklet
"Alfred and Uno meet the Customers" by Magnus Gustafsson.

Åbo Akademi University Press
Biskopsgatan 13, FIN-20500 ÅBO, Finland
Tel. int. +358-2-215 3292
Fax int. +358-2-215 4490
E-mail: forlaget@abo.fi
http://www.abo.fi/stiftelsen/forlag/

Distribution: **Oy Tibo-Trading Ab**
P.O.Box 33, FIN-21601 PARGAS, Finland
Tel. int. +358-2-454 9200
Fax int. +358-2-454 9220
E-mail: tibo@tibo.net
http://www.tibo.net

BUSINESS CONCEPTS BASED ON MODULARITY

Business Concepts Based on Modularity

A Clinical Inquiry into the Business of Delivering Projects

Magnus Hellström

ÅBO 2005

ÅBO AKADEMIS FÖRLAG – ÅBO AKADEMI UNIVERSITY PRESS

CIP Cataloguing in Publication

Hellström, Magnus
Business concepts based on modularity :
a clinical inquiry into the business of
delivering projects / Magnus Hellström. -
Åbo : Åbo Akademi University Press, 2005.
Diss.: Åbo Akademi University.
ISBN 951-765-294-1

ISBN 951-765-294-1
ISBN 951-765-295-X(digital)
Åbo Akademi University Printing House
Åbo 2005

ACKNOWLEDGEMENTS

The underlying work has been carried out at the Industrial Management Laboratory at the Faculty of Chemical Engineering at Åbo Akademi University (ÅAU), within the cooperation agreement between ÅAU and the Research Institute for Project Based Industry (PBI). I like to pinpoint two general benefits I highly appreciate in this constellation: the cross-disciplinary hotbed at ÅAU and the PBI-infrastructure where theory and practice can meet (to use the old dichotomy of Aristotle).

The reproduction of an explorative research journey often bears a nuance of *ex post*-reasoning. At times it even gives the wrong impression of the research process as it usually leaves out many of the trials and errors that might be as valuable for the scientific and managerial communities. I am still happy that this research has come to an end (and not become an intellectual journey without destination). For this and for so much more I am deeply indebted to many kind individuals:

- From a doctoral student point of view, one of the best things with Professor Kim Wikström, my supervisor, is the 'clinical research' infrastructure he has been developing for last decade or so. If it was not for the infrastructure, this research would never have started. If it was not for his inspiring enthusiasm for clinical research, this thesis would probably not have been finished.
- My namesake, Dr. Magnus Gustafsson, is often used as a sparring partner. For me he has been more than so, I would call him a mentor. His somewhat unconventional thoughts are not always easy to grasp. When you do, you are likely to find yourself generating new knowledge.
- My two reviewers, Professor Harri Haapasalo and Dr. Tim Brady, have truly worked to improve the quality of this work. Through their comments, new perspectives on my research have opened up. Furthermore, using athletics vocabulary, they made a strong finish. Tim, who will be my opponent, may still have a few words to say…
- This thesis is definitely a result of a collective effort. I have been happy to work together with several capable colleagues somehow connected to PBI and the Industrial Management Laboratory. In particular, I like to mention Thomas Westerholm for his support in some of the crucial studies this thesis is based on.
- A very special 'thanks' goes to the many practitioners who have engaged in this work. Through their demand, interest and critique this thesis at least aspires to be something more than a theoretical curiosity.
- During several conferences, seminars and the like, I have had the great opportunity to meet a group of distinguished scholars, who have in one way or another influenced my thinking of this research. I like mention especially, in order of appearance: Dr. Mats Engwall, Dr. Anders Söderholm, Professor Karlos Artto, and Professor Henrikki Tikkanen.

- I am also grateful for the opportunity to discuss my thesis topics with many merited researchers of the CoPS research group during my short stay at the CoPS Innovation Centre at the Universities of Brighton and Sussex.
- A thesis project requires financial support. Such has been provided by:
    - Fortum Foundation
    - Finnish Doctoral Program in Industrial Engineering and Management
    - Foundation for Project Research (PBI)
    - Research Institute of the Åbo Akademi University Foundation
    - Walter Ahlström Foundation
    - Åbo Akademi University
- A thesis project also requires social support. My tired and hazy thoughts go for a last time during this project to all those dear relatives and good friends who have encouraged me in my scientific ambitions throughout the years. Perhaps most of all, I am indebted to my dear parents, Gunnel and Ole, not the least for raising me in the spirit that learning is both virtuous and interesting.
- Eventually, every researcher needs a life. I am lucky to share one, with another researcher that is, one that knows what it is like to be a doctoral student. Thank you, Kirsi, and more lately also Linnea.

Åbo, November the 30th 2005

Magnus Hellström
mhellstr@abo.fi

Post scriptum

Swedish: Vad nu då, när allt är slut? Det vet inte jag, förtillfället har jag inget mål, men det gör kanske gamle...(what then, when all is finished? I do not know, maybe…could help me out):

Min tanke genom rymder lopp,
Som förr den aldrig spanat,
Ett liv gick för mitt hjärta opp,
Vars tjusning det ej anat,
Min dag flög som på vingar bort,
O, vad min bok mig syntes kort

Den slöts, och kvällen likaså,
Dock glödde än min låga,
Jag fann så mycket återstå
Att forska om och fråga,
Så många dunkla föremål.
Jag gick till gamle Fänrik Stål.

Johan Ludvig Runeberg
Fänrik Ståls sägner

A world now beckoned, which my thought
Had never yet laid eyes on,
My life expanded as it sought
The magic new horizon.
Too short the book, for now my day
Took wings and flew without a stay.

I put the finished volume by,
The evening hours had dwindled,
But none the less my heart burnt high
With flame the spark had kindled.
So much there was to ask about –
But maybe Stål could help me out.

Johan Ludvig Runeberg
The Tales of Ensign Stål
(transl. Stork, Shaw & Broad, 1952)

TABLE OF CONTENTS

ACKNOWLEDGEMENTS V

LIST OF FIGURES X

LIST OF TABLES XIII

1 INTRODUCTION 1

1.1 BACKGROUND – TRENDS IN THE PROJECT-BASED INDUSTRY 1
1.2 PROBLEM FORMULATION AND RESEARCH QUESTIONS 4
1.3 AIM - EXPECTED CONTRIBUTION AND POTENTIAL RELEVANCE 7
1.4 RESEARCH APPROACH 7
1.5 BODIES OF KNOWLEDGE RELEVANT TO THE STUDY 14
1.6 OUTLINE OF THE STUDY 15

2 LITERATURE REVIEW 17

MODULARITY AND PRODUCT STRUCTURING 17

2.1 THE CONCEPT OF MODULARITY 17
2.2 DRIVERS BEHIND MODULARITY 24
2.3 PRINCIPLES AND METHODS FOR MODULARISATION 37
2.4 MODULARITY AND ORGANISATIONAL OUTCOMES 42

THE NATURE OF PROJECT BUSINESS 47

2.5 WHAT IS PROJECT BUSINESS 47
2.6 PRODUCT COMPLEXITY AND THE MANAGEMENT OF TECHNOLOGY 51
2.7 PRODUCTION CHARACTERISTICS: THE OPERATIVE ENVIRONMENT OF PROJECTS 53
2.8 INDUSTRIAL COORDINATION AND THE PROJECT MILIEU 56
2.9 CHARACTERISTICS, FUTURE AND IMPORTANCE OF PROJECT BUSINESS MARKETS 60
2.10 COMPETITIVE STRATEGIES: SYSTEMS INTEGRATION AND OTHER BUSINESS CONCEPTS 63

SUMMARY OF THE THEORETICAL IMPLICATIONS 70

3 RESEARCH DESIGN AND METHODS 75

3.1 THE CLINICAL RESEARCH PROCESS 75
3.2 METHODS OF DATA COLLECTION AND ANALYSIS 81
3.3 INTERPRETATION AND THEORY BUILDING 86
3.4 QUALITY CRITERIA FOR NON-POSITIVISTIC RESEARCH 88

4 CASE DESCRIPTIONS 89

4.1 THE SHIP CASE 89
4.2 THE ENERGY SYSTEMS CASE 115

5 DISCUSSION 133

5.1 TWO COMPLEMENTARY CASES 133
5.2 WHAT IS A 'GOOD MODULE' 135
5.3 HOW MODULARITY CHANGES THE DELIVERY PROCESS 145

6 CONCLUSION 153

6.1 CLOSING THE 'BLACK BOX' 153
6.2 THEORETICAL CONTRIBUTION 156
6.3 PRACTICAL IMPLICATIONS 157
6.4 METHODOLOGICAL REFLECTIONS 159
6.5 FUTURE PROSPECTS 161

REFERENCES 163

APPENDIX 1: THE EMPRICAL DATA SOURCES 183

LIST OF FIGURES

Figure 1-1 The product-process matrix (adapted from Hayes and Wheelwright, 1979; as modified in Davis, Aquilano and Chase, 2003) 2

Figure 1-2 The capital goods value stream (from Davies, 2004: 737) 4

Figure 1-3 The action research process (from Susman and Evered, 1978: 588) 12

Figure 2-1 Function and module types in product systems (from Pahl and Beitz, 1996: 435) 18

Figure 2-2 Different levels of modularisation in automobiles (from Hsuan, 1999: 200) 24

Figure 2-3 Factors influencing the migration toward/away from product modularity (from Schilling, 2000: 321) 25

Figure 2-4 An organisational model for delivering integrated solutions (Davies *et al.*, 2003: 17; Davies and Hobday, 2005: 242) 67

Figure 2-5 The framework: the product-process palette in project business 71

Figure 3-1 The research design of the thesis 76

Figure 3-2 The research process behind the thesis shown as a flow diagram 80

Figure 3-3 The positioning of the participating parties in the DENSY-project (for more information, see Hellström et al., 2005) 82

Figure 3-4 An example DSM from a auto engine case (Eppinger, 1997: 203) 85

Figure 4-1 The production process of a ship project (Andritsos and Perez-Prat, 2000: 32) 93

Figure 4-2 The information processes of a ship project (Andritsos and Perez-Prat, 2000: 34) 94

Figure 4-3 Frequency distribution of the priority between modularity drivers (for more information, see Hellström and Wikström, 2004) 97

Figure 4-4 Average benefit priority score and average expected improvement (for more information, see Hellström and Wikström, 2004) 98

Figure 4-5 Frequency distribution of the sub-supplier’s perceived role (for more information, see Hellström and Wikström, 2004) 100

Figure 4-6 Product-DSM of ship engine room (for more information, see Wikström *et al.*, 2005) 102

Figure 4-7 Modular and integrative wholes identified in the engine room (for more information, see Wikström *et al.*, 2005) 103

Figure 4-8 Re-structured DSM for the engine room (for more information, see Wikström *et al.*, 2005) 104

Figure 4-9 Product-DSM (structural interfaces) of the cabin area 105

Figure 4-10 Process-DSM of ship engine room (project design) (for more information, see Wikström *et al.*, 2005) 107

Figure 4-11 Process-DSM of ship engine room (basic & detail design) (for more information, see Wikström *et al.*, 2005) 108

Figure 4-12 Process-DSM of the cabin area (design) 110

Figure 4-13 Process-DSM of the cabin area (installation/manufacturing) 111

Figure 4-14 Process-DSM of the theatre area (basic and detail design) (for more information, see Hellström and Westerholm, 2005) 112

Figure 4-15 Process-DSM of the theatre area (installation) (for more information, see Hellström and Westerholm, 2005) 113

Figure 4-16 The change of the optimal plant size in power business (Linden, 1997: 16) 115

Figure 4-17 A power plant delivery perceived from an integrated product and process breakdown 119

Figure 4-18 The distribution of the arguments of different players in the value chain/stream (for more information, see Hellström *et al.*, 2005) 120

Figure 4-19 The scope division seen in a product and process breakdown (for more information, see Hellström *et al.*, 2005) 122

Figure 4-20 Product-DSM of a boiler-based power plant (for more information, see Gustafsson *et al.*, 2005) 125

Figure 4-21 Re-structured product-DSM for the boiler plant (for more information, see Gustafsson *et al.*, 2005) 126

Figure 4-22 A DSM showing the information structure of the design activities in a power plant project (for more information, see Gustafsson *et al.*, 2005) .. 127

Figure 4-23 A DSM showing the information structure of the installation activities in a power plant project (for more information, see Gustafsson *et al.*, 2005) .. 128

Figure 4-24 The delivery seen as a network diagram (for more information, see Gustafsson *et al.*, 2005; Hellström *et al.*, 2005) 130

Figure 4-25 The delivery seen as a GANTT-chart (for more information, see Gustafsson et al., 2005; Hellström et al., 2005) 131

Figure 5-1 Categorisation of projects according to type of site and objective (Wikström, 2000: 15)... 134

Figure 5-2 From opposite sides 137

Figure 5-3 Modularity as a basis for customisation in project business..................... 138

Figure 5-4 A framework for the management of modular project deliveries (for more information, see Hellström and Wikström, 2005)...................................... 147

Figure 5-5 A schematic perception of “black boxes” using the DSM 148

LIST OF TABLES

Table 2-a Advantages of modularity (from Pahl and Beitz, 1996: 447) 31

Table 2-b Disadvantages of modularity (from Pahl and Beitz, 1996: 447-448) 34

Table 2-c Modularity in computers and autos compared (from Sako, 2003: 249) 46

Table 2-d CoPS versus mass-production (Hobday, 1998: 699) 50

Table 2-e Comparing seller and buyer perspectives of the project marketing cycle (Cova and Holstius, 1993: 111) 62

Table 2-f Evolution of project management (Laufer et al., 1996: 190) 68

Table 3-a The empirical data of the thesis 78

1 INTRODUCTION

Standardisation and related mass production has been the backbone of 20th century industrial activity. Customer taste, desire and need however remain individual. This contrast is at the core of most management research. One of the most celebrated approaches to balance these opposite forces is modularity, which especially as a product design strategy has rendered considerable success for instance in the personal computer and automotive industries. However, in project business the industrial practice still builds on tailored solutions. In this partly neglected but important area of industrial activity, modularisation seems to be met with suspicion and seen as a synonym for standardisation. In this thesis my aim is to show that even for big, capital projects there is a balance to be found. More specifically, I shall attempt to show how this balance can be found, as well as pursued as an economically sense-making activity.

1.1 Background – trends in the project-based industry

It is often claimed that many project management theories draw on the one-off and large-scale projects in the 1950s (Maylor, 2001; Engwall, 2003). In traditional operations management literature projects are mostly considered as a pre-phase to production, such as the development of a product or the construction of a production facility (see e.g. Buffa and Sarin, 1987; Chase and Aquilano, 1992), in other words, the creation of something unique. It can be said that this reflects an owner-view of project management. However, much as a result of the focus on core competencies and subsequent outsourcing among capital good owners, we have during the past decade experienced an accelerated trend towards turnkey-contracting in project business. As some project scopes are contracted more or less repetitively on a turnkey-basis, specialised suppliers of certain products and services (or combinations of the two) have evolved. Also such companies today term their deliveries projects, maybe in order to stress customer orientation, and the temporary characteristics of and uniqueness in projects. Midler (1995) terms this general phenomenon the "projectification" of the firm. Artto *et al.* (1998) suggest that, in fact, any attempt that is perceived as significant and important from the customer point of view could be termed a project. This way, big projects can be seen as constituting of several sub-projects, in turn.[1]

Clearly, projects have become a vehicle in the company's production line, more than merely a means for creating something unique. More precisely; in the case of the creation of such large, engineering-intensive capital goods this thesis is concerned with, projects can be seen as a means for a kind of collapsed development and production (Hobday, 1998). For the suppliers of such projects, pushed by a demand for faster and cheaper deliveries, it has become imperative to develop there products and processes to correspond to the repetitive nature of their business. Still, customisation remains a basic attribute in delivery projects. In terms of Hayes's and Wheelwright's classical map (as depicted in Figure 1-1) we can see a movement from the upper left category towards the right. In other words, we are talking about projects that are not purely unique and volumes somewhere in the "grey zone" between one-off and high volume. It can be claimed that the major part of all projects belong to this category.

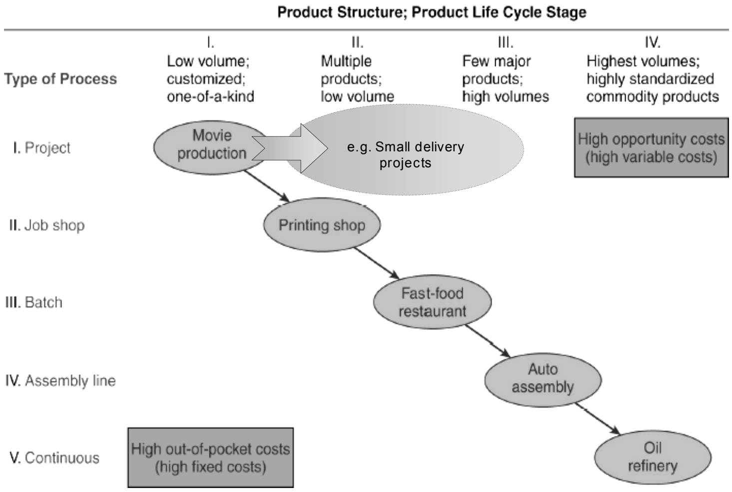


Figure 1-1 The product-process matrix (adapted from Hayes and Wheelwright, 1979; as modified in Davis, Aquilano and Chase, 2003)

---

[1] Even many high volume industries have switched to a project-mode of doing business (Iskanius, Haapasalo and Alaruikka, 2004).

The more common multi-project context and the more repetitive nature of projects imply a potential for realising benefits usually associated with mass production. However, due to the still relatively short series the same kind of standardisation as in mass production is rarely possible in the project-based industry. What is generally referred to as “modularity” or “modularisation”, is often advocated as a key for achieving a balance between standardisation and customisation in projects (Schimmoller, 1998; Meklin *et al.*, 1999; Nilsson, Blomquist and Wikström, 1999; Wikström and Storholm, 1999; Wikström, 2000; Brusoni and Prencipe, 2001; Hoare and Seiler, 2001; Alf and Menapace, 2002).

Another contemporary, related phenomenon in business is the increased emphasis on the utility, service aspects of a product (e.g. Normann, 1984; Grönroos, 1994). Project business is clearly a mix of goods and services. Consequently, there has been an increase in the scope of services offered by the supply side; a “movement downstream” (Wise and Baumgartner, 1999). Beginning with Mattsson (1973), researchers in industrial marketing have studied this phenomenon under the label of systems selling, which deals with the supply of integrated goods and services, or as it in today’s customer oriented business community is termed, “integrated solutions” (Wise and Baumgartner, 1999). The idea is to provide whole solutions to customers’ problems, rather than merely selling physical goods (Foote *et al.*, 2001). The term “integrated solutions” is especially well-suited for large, engineering intensive capital goods, where systems integration is seen as one essential capability (Davies *et al.*, 2001). In addition to the system product, such integrated solutions might include a variety of services such as financing, operation and maintenance as well as technical and business consulting according to Figure 1-2.

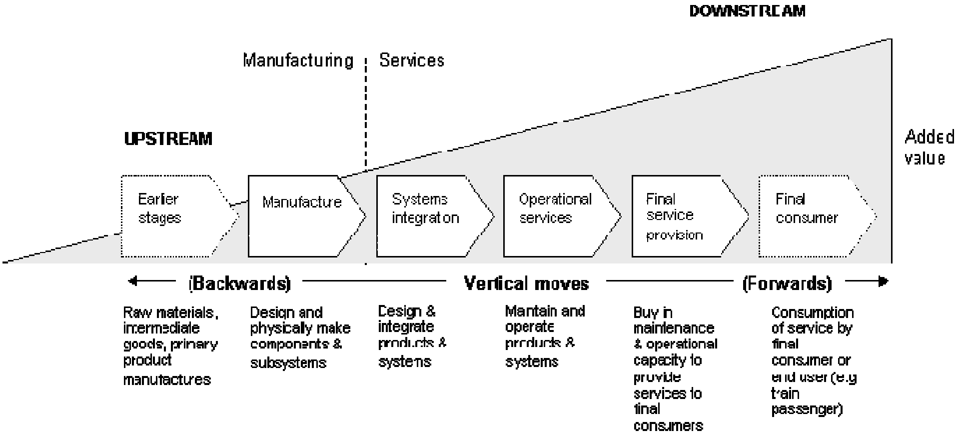


Figure 1-2 The capital goods value stream (from Davies, 2004: 737)

All the above can in part be considered symptoms of “the new logic of value” launched by Normann and Ramirez (1993). According to them it breaks down the distinction between products and services, suppliers and customers, knowledge and capabilities, and allows these to be configured into so called “value constellations” (rather than value chains). To be cost-effective this obviously requires a well structured offering, e.g. so called “naked solutions” that can be extended by add-on modules (Anderson and Narus, 1995: 76), and a pursuit for the creation of so called “repeatable solutions” (Davies and Brady, 2000). Modularity also lies at the core of the solution provider-model presented by Foote *et al*. (2001). They make a clear distinction between capability-based back-end units and customer-based front-end units. According to their vision, the role of the back-end units would be among other things to standardise and modularise products to be solutions-ready, whereas the task of front end units would be to work with customers and configure the products in to solution-packages.

1.2 Problem formulation and research questions

The idea of balancing the forces of customisation and standardisation through modularisation is well known in literature and widely used in high volume industries (see e.g. Starr, 1965; Pine, 1992; Lampel and Mintzberg, 1996). However, the idea is not as easily implemented as it sounds, especially not in the project-based industry, where the products often can be classified as so called "complex products and systems[1]" (Hobday, 1998) or "large technical systems" (Hughes, 1983). The issue of modularisation is further complicated due to the typically very low volumes in this kind of industry and the demand for offerings with increased service content. Furthermore, the extensive life-cycle and the thereby exerted varying requirements of capital goods need to be considered when designing modular solution architectures in the project-based industry. On the practical side, we are clearly dealing with what Ackoff (1979: 103) termed "systems of problems, messes". Among others the following questions have been raised:

- What, actually, is a module?
- How should we take the diverse customer requirements into account?
- How should we create (more) modules?
- How should we manage 'modular' projects?

In short, there seems to be a lack of proven business models for companies increasingly assuming the role of systems integrators (Davies *et al.*, 2001), or companies increasingly relying on systems integrators to provide them with their operational infrastructure (Hobday, Prencipe and Davies, 2003b; Flowers and Hobday, 2005).

On the theoretical side, there is a growing body of knowledge on modularity covering a wide range of disciplines. The literature on modularity can be divided into two domains: one stemming from the disciplines of engineering design (basically mechanical engineering) and the other covering a number of management disciplines. The former draws heavily on the concept of "product architecture" (Clark, 1985; Ulrich, 1995) and is typically concerned with establishing guidelines and methods for the process of modularisation, i.e. creating a modular architecture (see e.g. Pimmler and Eppinger, 1994; Erixon, 1998; Stone, 2000; Dahmus, Gonzalez-Zugasti and Otto, 2001). Except for the work of Eppinger and his colleagues (Pimmler and Eppinger, 1994; Eppinger, 1997; Sosa, Eppinger and Rowles, 2003) such methods are mainly developed with consumer goods that allow for mass-production in mind, typically emphasising the manufacturability aspect. Existing literature gives very few examples of successful modular or platform solutions in capital goods (see e.g. Storholm and Wikström, 1995; Schimmoller, 1998; Hoare and Seiler, 2001; Alf and Menapace, 2002). A key driver behind modularity is standardisation, because it results in economies of scale. These are difficult to achieve in project-based industries, which means that

---

[1] Often abbreviated CoPS; Hobday (1998) describes CoPS as "high cost, engineering-intensive products, systems and networks and constructs".

modularisation probably has to be approached differently. For example, manufacturability is likely to be only one of the concerns in the typically long life-cycle of projects.

Management literature on modularity on the other hand, has covered topics such as product variety and mass customisation (Starr, 1965; Pine, 1992); marketing (Sanchez, 1999); strategic flexibility (Garud and Kumaraswamy, 1995; Sanchez, 1995); technological innovation, knowledge management and vertical integration (Langlois and Robertson, 1992; Sanchez and Mahoney, 1996; Prencipe, 2000; Schilling, 2000; Brusoni and Prencipe, 2001; Brusoni, Prencipe and Pavitt, 2001; Schilling and Steensma, 2001); and supply chain management and vertical integration (Novak and Eppinger, 2001; Fredriksson, 2002; Gadde and Jellbo, 2002; Doran, 2003). However, only little published research is explicitly concerned with the project-based industry and its unique characteristics (e.g. Prencipe, 2000; Brusoni and Prencipe, 2001; Brusoni *et al.*, 2001). These unique characteristics are well documented in literature (see e.g. Cova and Holstius, 1993; Lundin and Söderholm, 1995; Miller *et al.*, 1995; Bonaccorsi, Pammolli and Tani, 1996; Hadjikhani, 1996; Hobday, 1998; Wikström and Gustafsson, 1999; Hobday, 2000).

In sum, both streams of literature on modularity seem relevant in respect to the mess of practical problems mentioned above, but neither of them deals explicitly with modularity in project-based industry. Moreover, as modularity seems to be a rather neglected topic in the project management literature, the need for an exploratory study can be justified. Thus, with regard to the implementation of modularity the following research question is posed:

Q1) What is a 'good module' in projects?

This question entails an inquiry into both the way modularity is perceived and how modules emerge and form in the specific industry context under scrutiny. The unit of analysis is the product, on the one hand, and the delivering organisation, on the other; or more precisely, by looking at the business as a whole and the nature of the product, what can be said about how the product is and should be?

Well implemented, modularity is likely to change the way projects are managed. The second part of the thesis is thus to cover issues concerned with:

Q2) How does modularity change the delivery process?

Here the unit of analysis lies at two interacting levels: the individual project, and the project organisation as a whole; more precisely, by looking at the product, what can be said about the way of delivering both a single project, and a set of more or less repetitive projects (i.e. a multi-project context)?

1.3 Aim - Expected contribution and potential relevance

Whereas question 1 deals with the issue of structuring the product, question 2 entails an interest in both the way individual projects are managed, i.e. the issue of project management, and, maybe even more, an interest in the way project-based industries are organised. The thesis could therefore be seen as an inquiry into viable business models based on modularity for project-intensive organisations. The choice of the thesis subject is justified by and rests on the belief that the structure of the product determines to some degree the way the delivery should be managed and organised, an idea which dates back as far as Adam Smith (1776) and the division of labour, and which has gained considerable attention also in more recent research (Henderson and Clark, 1990; Sanchez and Mahoney, 1996; Hobday, 1998; Brusoni *et al.*, 2001; Novak and Eppinger, 2001; Oosterman, 2001; Sosa *et al.*, 2003; Sosa, Eppinger and Rowles, 2004).

The theoretical contribution of this research project is expected to lie in the synthesis of the theories on project business and modularity, or in other words, the desire is to increase our understanding of the 'grey zone' between one-off and mass-production, as illustrated in Figure 1-1. More specifically, the thesis aims at a description of the problems and the possibilities to create a modularised product-process structure (i.e. project structure) in an industry with low production volumes and long product life cycles.

The practical benefit of this work will hopefully emerge through the clinical fieldwork undertaken in order to collect and analyse empirical data. In general, the relevance of this study is likely to reside in new business models for an industry struggling with uncertainty, high risks and fluctuating profitability.

1.4 Research approach

The methodological account of this thesis follows Denzin and Lincoln's (1998) general description of the (qualitative) research process. They define it in the following 'phases[1]':

---

[1] This is not to be seen as a strict chronological order as the phases may overlap and definitely do interact.

- Phase 1: The researcher as a multicultural subject (section 1.4.1)
- Phase 2: Theoretical paradigms and perspectives (section 1.4.2)
- Phase 3: Research strategies (section 1.4.3 and section 3.1)
- Phase 4: Methods of collection and analysis (section 3.2)
- Phase 5: The art of interpretation and presentation (section 3.3)

In this section, I will mainly discuss the issues in the first two phases. I will also briefly outline the research strategy for the underlying study (Phase 3) and present some specific methodological approaches important for it. The reader is referred to chapter 3 for the details of the research design of this study (Phase 3-5).

1.4.1 Personal background and research traditions in the subject area

This thesis is interdisciplinary, spanning over fields such as product development, production, industrial marketing, and organizing. To be strict however, it mainly draws upon the classical academic discipline of operations management (including the sub-discipline of project management). At least this is the field in which I have received my basic training as an engineer and it is probably fair to say that this background provides a starting point for the research journey ahead. Traditionally operations management has relied on theory testing research, using mathematics, modelling and simulation (Scudder and Hill, 1998), also referred to as "rationalist methods" (Meredith, 1998). More recently the interest in more "qualitative", empirical research, especially case studies, seems to have grown (Westbrook, 1995; Meredith, 1998; Scudder and Hill, 1998; Voss, Tsikriktsis and Frohlich, 2002). Such "qualitative" methods are typically perceived as a way to deeper understanding (Meredith, 1998) and practical utility (Westbrook, 1995). These are also personal desires with regard to the underlying research problems, that is, somehow acknowledging that the area of the study lies in the twilight between engineering and business administration, or incisively put, between (scientific) explanation and (human) understanding (von Wright, 1971). Although being trained in a field that is based on the laws of physics, my professional experience from the subject area (see APPENDX 1) tells me to question a too deterministic view to the order social affairs, such as the construction of a power plant in the country side of Tamil Nadu in south India. In fact, in science and technology studies - a sociological relative to the engineering design-wing of operations management - there is a growing body of literature pinpointing the socially constructed nature of not only social affairs, but also both science and technology (see e.g. Bijker, Hughes and Pinch, 1987; Latour, 1987).

Undoubtedly, also the extant literature on modularity has influenced my thinking of the subject. Literature gives examples of a variety of methodological approaches, which do not allow themselves to be easily categorised in terms of used inquiry paradigms. But a review of the major contributions on the topic reveals that the case-method accounts for most of the works. More specifically, the management stream seems to have favoured a case-based and/or theoretical reasoning approach (Langlois and Robertson, 1992; Sanchez and Mahoney, 1996; Baldwin and Clark, 1997; Brusoni and Prencipe, 2001), especially drawing upon systems and complexity theory (Sanchez, 1997; Schilling, 2000; Langlois, 2002). The engineering design-field, on the other hand, has clearly adopted a quite practice-logical, heuristic line of reasoning, often striving for high practical utility (Pimmler and Eppinger, 1994; Erixon, 1998; Stone, 2000), although works using mathematical modelling have also evolved (Sosa *et al.*, 2003; Hsuan Mikkola, 2004).

In section 1.2, different units of analysis: the large-scale product, the project and the project organisation (or as well the industry structure as a whole) were discussed. Given the inherent complexity in large-scale, technical systems (Hughes, 1983; Davies, 1996; Hobday, 1998), and the, by definition, unique nature of projects, it seems that such units of analysis will not easily allow for far reaching, abstract generalisations. Instead they would probably benefit from more descriptive studies pinpointing different systemic natures of technology (Sosa et al., 2003) and from "thick descriptions" (Geertz, 1973), revealing underlying social constructions (Bijker *et al.*, 1987; Latour, 1996) and the dynamic nature of social life (Latour, 1987). Using the same line of argument the organisational and industrial units should be even more unique and complex. Considering that projects are much about human action and relationships (Gustafsson, 2002) and industrial markets (including project organisations) typically based on networks of relationships (Gadde, Huemer and Håkansson, 2003), a method capable of capturing the complexity of these issues should be favoured. Ideally, an interpretive (see e.g. Winch, 1958) approach to understanding social life at the level of the individual ought to be chosen. However intriguing and enlightening, this lies beyond the objectives of this study, which will not be concerned with the human being as the unit of analysis.

1.4.2 Philosophical assumptions and methodological perspectives

As for the more philosophical issues in Phase 2, simply describing this research as qualitative in nature (in contrast to what is generally referred to as "quantitative research"), will not say much about the fundamental underpinnings of it (Silverman, 1997; Denzin and Lincoln, 1998). Largely thanks to the work of Thomas Kuhn (1962), it has become customary among social scientists to start off by confessing 'paradigmatic belief'. This is what this section will reflect upon.

Contrary to Kuhn's ideas, Burrell and Morgan (1979) claimed that different scientific paradigms can be pursued concurrently in the social sciences, although incommensurable among themselves. Their work has undoubtedly had a great effect on the healthy tradition that urges us to reflect upon the philosophical underpinnings of our research. However, their work can be criticised for its eclectic nature, not allowing any position between extreme foundationalism and the "anything goes"-relativity of postmodernism. Such an intermediate position would inevitably draw upon pragmatist and critical (realist) lines of thought. (Putnam, 1990; Gustafsson, 1994; Johnston and Duberly, 2000). Also Guba and Lincoln (1998) see a continuum of metaphysical choices between the two extremes, all of which will be determined by our response to the three fundamental and interconnected questions of ontological, epistemological and methodological standpoint.

Assuming the responsibility of contributing to the solution of practical problems, it seems only natural to adopt the "pragmatic-critical realism" standpoint envisaged by Johnston and Duberly (2000). According to them, this would entail an inclination towards a realist position in terms of ontology, or at least a rejection of complete relativism, while maintaining a subjectivist view to epistemology. Such a contradictory standpoint is admittedly difficult to sustain. Put in more concrete, simple terms, "truth" is in accordance with the pragmatist tradition taken to be a/the solution that works, or one that really makes a difference (Susman and Evered, 1978 referring to Charles Pierce, John Dewey and William James). This does, however, not mean that there would necessarily be only one single, ultimate truth in the state of social affairs, but rather several possible, more or less socially constructed, but essentially "functioning", realities.

The epistemological implications hereof are that the observer does not necessarily have to adopt an objectivist role, treating the studied object with kid gloves in order not to influence it in any way. Instead, a clinical intervention in the studied system might even be advantageous in order to solve the underlying problem (see e.g. Lewin, 1946; Normann, 1975; Susman and Evered, 1978; Clark, 1980). This, of course, necessarily renders the research subjective in a strict (positivistic) sense. Accepting such subjectivity should still not be seen as a deficiency, but rather as a conscious choice and a reflexive response to the fundamental problem with the objectivist criterion: the notion that theories, values and facts, and observers and objects, in practice are quite interdependent (see e.g. Guba and Lincoln, 1998). In other words, the above ontological and epistemological commitments go hand in hand with a dialectic methodological approach. This means a dialogue between the object and the observer, which in turn could give research a hermeneutical (interpretitive) nuance, when the collaboration is long and close enough in order to arrive at a, preferably shared, deeper understanding of the studied phenomenon.

1.4.3 Research strategy – a clinical approach

Indeed, the description of a strategy for an explorative research effort is often coloured by *ex post*-reasoning. So is the case of this thesis. The underlying *bricolage*[1] could, however, best be described as an clinical case(s) study (see Normann, 1975; Schein, 1995), partly basing its legitimacy as a method on action research. The clinical approach has been applied on two cases from different kinds of project-based industries: ship building and energy systems delivery.

The American sociologist Kurt Lewin is often regarded as 'the father' of action research. Since his days the methodological approach has scattered, but the concept still remains "an umbrella term for a shower of activities intended to foster change" (Dickens and Watkins, 1999), by contributing to the solution of practical problems (Clark, 1980). The various approaches differ, not least, in terms of the three, metaphysical questions explained above. Well-established variants of Lewin's approach of interest for this study are for instance "action science" (Argyris, 1995), "clinical research" (Normann, 1975; Schein, 1995), "processual consultation" (Schein, 1995), "process research" or "processual analysis" (Pettigrew, 1990; 1997) and "the constructive approach" (Kasanen and Lukka, 1993; Kaplan, 1998).

Another distinctive feature of action research, despite fostering change, is the way the researchers intervene in the change processes the studied object is going through (see e.g. Susman and Evered, 1978; Clark, 1980). Briefly speaking, my strategy has been to actively participate in these programmes by providing theoretical knowledge and different kinds of analyses regarding product and process structures, and to extract new theoretical insights from the co-operation with these two industries and from the comparison between the two cases. The difference to the more deterministic kind of research in operations management is, using Ackoff's (1979) words, that an action-oriented approach instead of merely 'predicting and preparing' rather strives to "design a desirable future and invent ways of bringing it about".

Action research is typically described as a cyclical process that based on a diagnosis of the current state prescribes some course of action to be taken and thereafter follows the change process in order to evaluate the appropriateness of the given prescription (see Figure 1-3).

---

[1] "Qualitative research" has often been described as a bricolage, and corresponding researcher a bricoleur (for a further discussion on these concepts, see Denzin and Lincoln, 1998).

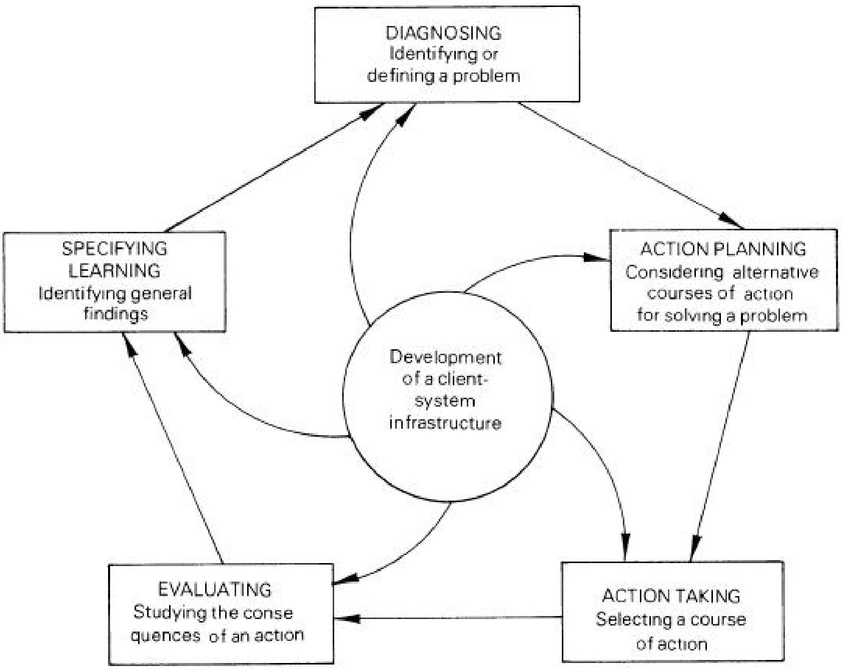


Figure 1-3 The action research process (from Susman and Evered, 1978: 588)

My thesis project contains many of the characteristics of the action research cycle. There are, however, two reasons why I prefer to specifically denote my approach clinical. First, as one of the main proponents of the approach, Edgar Schein (1995), sees it: the difference between clinical research and other action-oriented approaches is that it is (more) client-driven, and always entails an element of helping the actors with their problems, the initiative ultimately coming from them, and not like in typical Lewinian action research, from the change agent, who wish to study a particular, predetermined phenomenon. This is also reflected by the pathological parallel of clinical research, that is, the mindset that the clients' interests and welfare are of ultimate concern (Schein 1998). The clinical approach has been conceived by among others the Swedish-Scandinavian research-group SIAR, who build up an entire organisation (compare with the "client-system infrastructure" in Figure 1-3) carrying out applied research assignments (Rhenman, 1970; Normann, 1975; Lind and Rhenman, 1989). This study uses a similar platform developed at the Research Institute for Project-Based Industry[1] (PBI; see below). With regard to the above it can be agreed that the approach is very client-driven, however, maybe not to the extent

---

[1] PBI is a private, independent research institute with a close relation to Åbo Akademi University. The institute is owned by a foundation, which supports and promotes academic research in the project-based industry.

that Schein (1995) sees it. Rather the initiative can be seen as a joint effort between the client and the change agent, where the latter might recommend a certain course of action, often drawing on recent developments in research, before the need for help has been articulated (Wikström, 2005). This could maybe be seen as Schein's (1995) "confrontive inquiry", which forces the client to think about new ways of doing business.

The second reason why I prefer to use the term "clinical research" is a direct consequence of the first reason. Namely, action research implies a more strict, straight forward process driven by the researcher and proceeding in clear phases, whereas a process that is carried out on the conditions of a client (and consequently the situational complexities of his business) hardly can be as straight forward. This is probably why two acknowledged action-oriented researchers, Edgar Schein (1995) and Andrew Pettigrew (Pettigrew, 1990; 1997), emphasise the processual character of their research. Clinical research hence allows for a combination of the prescriptive and problem-solving characteristics of traditional action research and the descriptive character of case studies in general. It is also stressed that the clinical approach used in this thesis is not to be confused with another, perhaps more common, form of action research, namely participative action research (PAR). Except for my earlier employment in the energy systems industry, I have not been part of (i.e. employed by) the studied organisations.

Pettigrew (1997) considers neglect of method description and lack of analytical foundations a typical deficiency of action-oriented case study reports. He writes:

> *Process research is a craft activity full of intuition, judgement and tacit knowledge. Yet there are some identifiable rules of the game that can help structure its design, social process and presentation.* (Pettigrew, 1997: 346)

I will thus use the action research cycle as methodological framework when presenting the research design in section 3.1.

1.4.4 The Research Institute for Project-Based Industry (PBI)[1]

The whole set up described above and below in this chapter is enabled by the clinical research infrastructure established through the co-operation between the Research Institute for Project-Based Industry (PBI) and the Laboratory of Industrial Management at the Faculty of Chemical Engineering at Åbo Akademi University. Since its inception in 1993 PBI has been carrying out both applied and basic research on issues concerning international projects and the project-based company in close cooperation with both industry and academia. The close co-operation with industry has the possible downside that research is directed too much by the current agenda of

---

[1] This paragraph follows Wikström (2000) and Gustafsson (2002). For further information on PBI, see these sources.

the industry. This is, however, avoided through striving continuously for presenting the results on academic conferences and publishing in academic journals, and by incorporating academic researchers (such as PhD-students) in the projects. This unique constellation has enabled an approach where the results can simultaneously be tested for practical relevance and 'validated', or rather "falsified" as Karl Popper (1935) liked to see it, for theoretical contribution. According to Popper the best way to further science is not necessarily through induction, since, as he expressed it, where one thousand white swans cannot fully convince us of the fact that all swans are white, just one black swan effectively shows the opposite. Consequently, he thought that science is best progressed by presenting bold guesses that are to be falsified, that is, shown to be incorrect (rather than validated). As long as nobody succeeds in proving the guess as false it is to be taken as true. In fact, falsifying generated theories and concepts in real world test settings is to take research much further, I dare to say, than most social scientists ever think of.

Methodologically PBI's approach can be described as a basically inductive approach in combination with a Popperian scientific boldness in the conclusions. Perhaps one of the most striking features in the research process is, however, the fact that the research is carried out in groups, not only when it comes to data collection, but also in analysis and reporting, something that actually is not very common in social sciences in general. Hence, PBI is maybe best described as a tool or platform for real-time empirical research, providing means for data collection and analysis as well as theory and knowledge generation and testing, and it is largely in this function the organisation has contributed to this thesis.

1.5 Bodies of knowledge relevant to the study

Eisenhardt (1989) stresses the importance of comparison with extant literature, among others in order for us to find similarities and contradictions. An area of special interest is indeed the automotive industry, which for years has pursued modularisation in connection to extended enterprise structures (see e.g. Clark, 1989; Collins, Bechler and Pires, 1997; Dyer, 1997; Marx, Zilbovicius and Salerno, 1997; Piller and Waringer, 1999). This study spans over many adjacent fields: indeed, the vast body of knowledge on project management and product development will be used. Close to the latter comes the literature on engineering design, especially the work on modularity. Modularity has also been studied within the (strategic) management discipline. While the emphasis will lie in combining these two topics, the fact that many actors are involved in the studied projects, means the business network aspect cannot be ignored. Consequently some literature on supply (chain) management, purchasing and (out)sourcing will be considered. Finally, the increasingly popular service management literature is likely to be used to some extent. With such a mix of topics a carefully constructed framework will be important.

1.6 Outline of the study

Abductive studies are typically such that theoretical framework, empirical fieldwork, and case analysis evolve simultaneously (Dubois and Gadde, 2002b). This sometimes makes them difficult to structure according to the classical patterns of literature review - empirical part – analysis and discussion - conclusion. For the purposes of this study, I have decided to extract the two bodies of knowledge on modularity and project business from the rest of the text in Chapter 2. At the end of the chapter I combine the two bodies of knowledge and summarize some of the more important implications thereof into a loose, theoretical frame of reference, which should serve as deductive lenses through which the studied object is looked at (Alasuutari, 1999). Chapter 3 contains, as promised, a detailed account of the research process. It strives to describe the overall research design. Chapter 4 then provides the description and analysis of each case separately. In Chapter 5 I attempt a synthesis by comparing and combining the two cases and by discussing them in the light of the research questions. Finally, Chapter 6 summarises the conclusions, and outlines the contribution and the practical implications.

2 LITERATURE REVIEW

Modularity and product structuring

Modularity is not a new concept. Over the years its meaning and application has, however, changed. The purpose of this chapter is to define the concept by describing the rationale for the different uses of it. I will also discuss different methods as to how modularity can be achieved. Finally, my review will cover the topic of the impact of modularity on organisational issues.

2.1 The concept of modularity

2.1.1 The evolution of the concept

Originally the term module had a purely structural meaning. It was derived from the Latin word *modulus*, which was a unit of measure in classical architecture (Bartleby.com, 2004). Although the usability aspect of architectural artefacts was recognised even in ancient Roman times, the idea of combining standardisation with functional thinking received more attention only in the beginning of the 20th century through the paradigm of *Functionalism*, pioneered by the Bauhaus school. Functionalist architects of the Bauhaus school strove to consider not only the functional requirements of the users but also those of industrial production in building construction. The module was linked to the concept of a building block (in German: *Baukasten*). It was soon realised that the productivity of building was greatly improved when the building components were prefabricated, instead of making them on the building site at difficult locations and subject to unpredictable situations. This, in turn, made it possible to mass-produce certain building blocks and to thereby achieve economies of scale. This of course required products that did not vary much. The functionality of the building block was not directly connected to the module during the Bauhaus era, as the module still was only related to the geometry of the interface. The module as a standard measure of length is still today used in architecture and construction. (Routio, 1995).

More recently and especially in the area of mechanical engineering and engineering design, the linkage between modules and technical functions has been emphasised. Pahl and Beitz (1996) define modular products as "machines, assemblies and components that fulfil various overall functions through the combination of distinct building blocks or modules". They moreover make a distinction between production modules and function modules; the production modules being similar to the structural approach and the idea of *Functionalism*. However, they contend that this division is neither clear-cut nor adequate for the development of modular systems. Instead they elaborate further on the function-view and propose a classification into basic, auxiliary, special, adaptive, customer specific functions, each in connection to corresponding module (or non-module) as depicted in Figure 2-1.

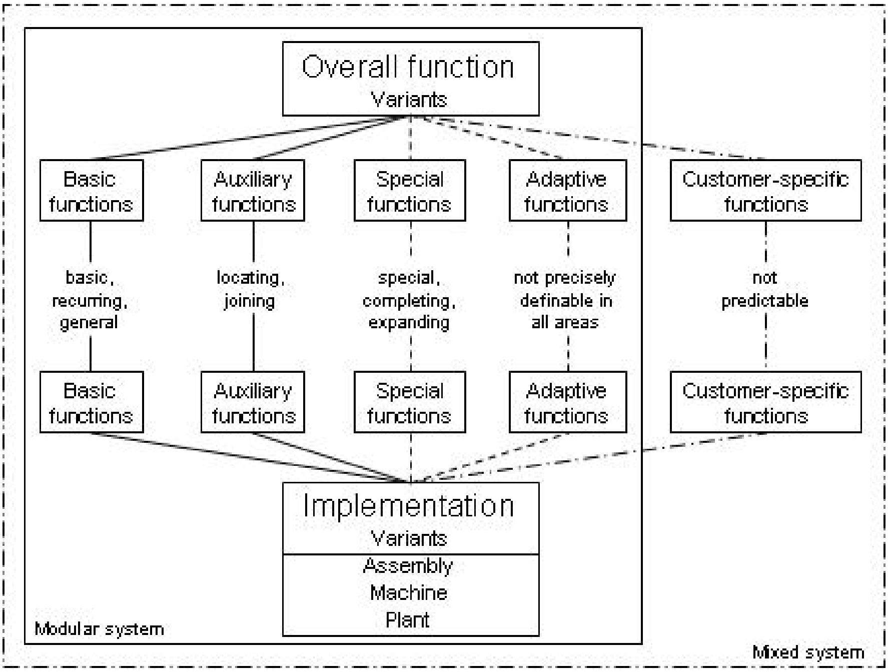


Figure 2-1 Function and module types in product systems (from Pahl and Beitz, 1996: 435)

Ulrich (1995), in turn, makes the distinction between modular and integral product architectures based on the central concept of "function structure", which he (1995: 421), consistent with Pahl and Beitz (and Hubka and Eder, 1988), defines as the "arrangement of functional elements and their interconnections". Following this logic Ulrich defines a modular architecture, in contrast to an integral architecture, as one where each function (or functional element) is mapped to one (or few) physical components (e.g. modules), and which specifies de-coupled interfaces between components. As Sako (2003: 231) notes, although the distinction between integral and modular product architectures is conceptually powerful, it might be "difficult to rank different combinations of characteristics along a modular-integral spectrum". Still, one important contribution of Ulrich's (1995) work is the further conceptualisation of Clark's (1985; Henderson and Clark, 1990) notion of (product) "architecture", which he defines as "the scheme by which the function of a product is allocated to physical components". Whereas Henderson and Clark (1990) focus on innovation in relation to component versus architectural knowledge, Ulrich furthers our understanding of product architectures in relation to design and manufacturing.

It is to be noted the meaning of the term "function" here is slightly different from the meaning attached to the concept above in the discussion of the architectural paradigm of *Functionalism*. There we were concerned with the functionality of a component with regards to either the consumer or producer of it. In this section the term refers to a mechanical, or rather technical (as it arguably also can be e.g. chemical, electrical or electromechanical), function. For the purposes of this text, I prefer to use the words "functionality" or "functionalism" for the former and the word "function" for the latter.

As we have seen certain streams of the Bauhaus tradition finally became more of a symbol of standardisation than modularisation. Contemporary was the industry evolution within the automotive industry. The strong drive towards mass-production of standardised goods is often seen as one factor behind the success of many big US companies in the 20th century. However, when taken to its extreme the movement was soon found incomplete and already in 1965 Martin Starr in a Harvard Business Review article talked about a new concept, namely that of "modular production", or what he also called "combinatorial productive capacities", which was supposed to give consumers greater variability. This stream of practice is today commonly labelled mass-customisation (Davis, 1987; Pine, 1992). Simply put, mass customisation is a strategy that strives to enable high, but restricted variety by mixing and matching a limited number of sub-components.

During the past decade, scholars in both economics and business administration have begun to further explore the effects of modularity on how businesses, business networks and whole industries are organised in terms of knowledge management and innovation (Langlois and Robertson, 1992; Sanchez and Mahoney, 1996; Brusoni and Prencipe, 2001; Schilling and Steensma, 2001; Langlois, 2002). Furthermore, the use of the term "module" has become ever more common. For example, it is frequently used to describe optional alternatives in certain service offerings, such as financial instruments and course-packages (see e.g. Baldwin and Clark, 1997; Piller and Meier, 2001). Clearly, as Sanchez (1997) indicates and Schilling tells us:

> *Modularity is a general systems concept; it is a continuum describing the degree to which a system's components can be separated and recombined.* (Schilling, 2000: 312)

Before examining the drivers and anti-drivers of such systems, I will attempt to define the concept of modularity.

2.1.2 Definitions of modularity

There are a great number of definitions of modularity available. In practical terms they all contain some or all of the elements discussed above and below. Let us begin by briefly considering some general definitions of modularity. The Merriam-Webster Online Dictionary provides us with a quite extensive definition of the word "module":

> *1: a standard or unit of measurement 2: the size of some one part taken as a unit of measure by which the proportions of an architectural composition are regulated 3 a: any in a series of standardized units for use together: as (1): a unit of furniture or architecture (2) a: an educational unit which covers a single subject or topic b: a usually packaged functional assembly of electronic components for use with other such assemblies 4: an independently-operable unit that is a part of the total structure of a space vehicle 5 a: a subset of an additive group that is also a group under addition b : a mathematical set that is a commutative group under addition and that is closed under multiplication which is distributive from the left or right or both by elements of a ring and for which a(bx) = (ab)x or (xb)a = x(ba) or both where a and b are elements of the ring and x belongs to the set* (Merriam Webster Online, 2004).

For comparison, The Columbia Encyclopedia gives the following general explanation of the word "module":

> *1 Term derived from the Latin modulus, a unit of measure in classical architecture equal to half the diameter of a column at its base. This unit was used in proportioning the classical orders of architecture. 2 The modern module is an interchangeable building unit used in construction; these units are mass-produced and therefore easily replaced and economical* (The Columbia Encyclopedia, 2004).

This may serve as a base for the case of product modularity, for which I turn to more specific definitions found in management and engineering literature. Much of the literature on modularity addresses some, but not all, of the relevant characteristics (Sako, 2003). As we have seen earlier in this chapter, different authors emphasise different aspects of modularity, often according to their specific field of study. Obviously then, we should be looking for a definition that covers all of these aspects, as they all seem relevant for the underlying study. Ulrich's (1995) product architecture-based definition is probably one of the most cited ones. Although it merely focuses on the one-to-one function mapping, it is logically coherent and conceptually strong. However, it is also 'idealistic' and definitely product centric. Erixon provides a broader and more practically-oriented definition is given:

> *…product modularity is defined using two characteristics: 1) Similarity between the physical and functional architecture of the design and 2) Minimisation of the degree of interaction between physical components* (1998: 53).

Erixon continues:

> *Hence (…) the definition of modularization is: decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific strategies* (1998: 58).

One could argue that Erixon extends Ulrich's (Ulrich and Tung, 1991; Ulrich, 1995) definition. For comparison, the function-view is more explicitly included in the definition provided by Miller and Elgård, who in turn have left out the notion of reducing complexity by minimising interdependencies:

> *A module is an essential and self-contained functional unit relative to the product of which it is part. The module has, relative to a system definition, standardized interfaces and interactions that allow composition of products by combination.* (Miller and Elgård, 1998: 16).

In addition, Miller and Elgård define modularity as an attribute for a system of modules, and modularisation as the activity of structuring in modules.

Drawing on her studies in the automotive industry, Sako likes to emphasise the unit-whole relation in the two above definitions by making it a third characteristic:

> *Modularity (…) is a bundle of characteristics that define (a) <u>interfaces</u> between elements of the whole, (b) a function-to-component (…) mapping of that defines what those elements are, and (c) hierarchies of decomposition of the whole into functions, components, tasks etc.* (Sako, 2003: 230).

One could of course question the hierarchy-characteristic, but interpreted broadly a module indeed makes its meaning as a part of a whole. In the same sense one could question the interdependency-characteristic in Erixon's (1998) definition. On the other hand, without it a module would be the same as any sub-assembly or subsystem. The notion of sub-assembly, which is a direct consequence of the hierarchy-characteristic, is of great importance especially in the automotive industry, where a module often is equalled with a physical subassembly (Mercer, 1995; as quoted in Collins *et al.*, 1997). Erixon however wants to make a clear distinction between module and subassembly. According to him:

> *A subassembly is often the result of the assembly planning activity. Subassemblies are created because the product design does not permit entire assembly in one flow. The need for many subassemblies may be one of the first indicators of poor product design. A module, however, is chosen for specific, corporate strategic reasons and the interfaces should take the ability to be assembled into account. It is often beneficial to subassemble the module off-line of the final assembly line. Consequently, a subassembly is not necessarily a module, but a module is often a subassembly.* (Erixon, 1998: 58).

Thus, a subassembly corresponds to what Pahl and Beitz (1996) call "production module".

To sum up, we are left with the following characteristics of modularity:

1) interfaces that fit together – both geometrical and other kinds of interfaces
2) function – each module is linked to a (restricted amount of) technical function(s)
3) hierarchy – each module is part of a bigger whole
4) minimised interdependencies

What we lack in the three definitions quoted above is merely the customisation driver as well as the notion of standardisation and mass-production of the module itself, i.e. what Rutenberg (1971) termed "commonality" among product variants. Arguably, however, these are not necessary characteristics for modules, although from the practical economical point-of-view they probably are prerequisites and most important drivers behind modularity. This is probably partly what Erixon (1998) means by "driven by company-specific strategies" in his definition above. On the one hand, if we omit the drive for economies of scale and variability from the definition we see modularity mainly as a means for managing complexity. On the other, if we include standardisation and customisation in a definition, it looks like this:

> *Product modularity is a systems design strategy that can be used to 1) manage complexity by hierarchically decomposing a whole into parts and by mapping functions to parts in order to minimise interdependencies, to thereby enable the pursuit for 2) economies of scale by standardising such parts and 3) variability through standardised interfaces that allow the use of interchangeable such parts, or 4) other such benefits.*

The first three are probably the most commonly known attributes of modularity. As indicated, however, there are more benefits that a company can harvest through modularisation. For each company or industry that wants to pursue a modularisation strategy more important than a proper definition is to define what benefits it seeks to achieve by 'going modular'. Or more broadly, as Ulrich (2003) himself comments on his own seminal article from 1995: product architecture is one of the key decision variables of the firm. This is shown in practice by a series of works concerning supply chain efficiency (Lee, 1996; Kaski, 2002).

The discussion on modularity so far is thought to provide a reference frame when trying to understand how organisations go about creating and using modules, processes that supposedly are not only matter of applying scientific facts. Indeed, as we already have seen, it is difficult enough to find a common, general definition of modularity. And even if it was possible to find one, it would most likely entail imprecise or ambiguous wordings like "de-coupled", "few" or "minimize".

2.1.3 Product hierarchies and levels of modularity

Hsuan (1999) makes an important contribution to the concept of modularity when she talks about "levels of modularisation". In Figure 2-2 she distinguishes between four such levels: the component, module, sub-system and the system level. According to her modularisation can take place at all these levels[1]. This is of course a direct consequence from the idea that most systems (Simon, 1962) and objects (Alexander, 1964) can be seen (and/or modelled) as hierarchies. Sosa *et al.* (2003) show a practical consequence of this line of reasoning by distinguishing between modular and integrative components on the one hand and modular and integrative systems on the other. The notion of modular (or integrative) systems is particularly relevant for the capital goods business, where the products often consist of several sub-systems and components.

---

[1] Of course, talking about modularity on the highest system level would be pointless as discussed above, as it then no longer would be a part of a greater whole.

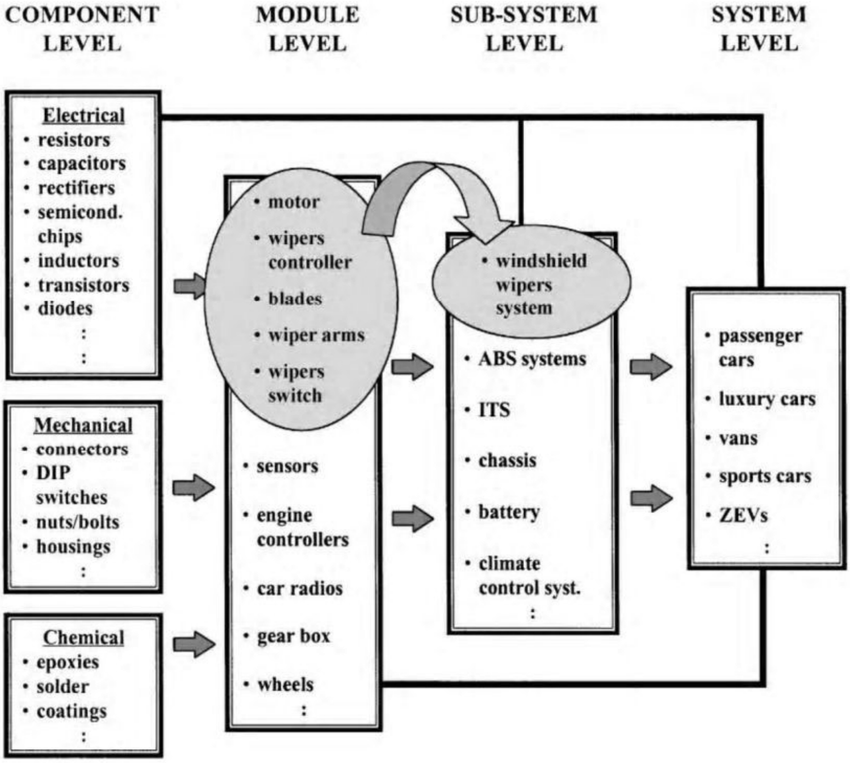


Figure 2-2 Different levels of modularisation in automobiles (from Hsuan, 1999: 200)

2.2 Drivers behind modularity

2.2.1 Modularity as general systems attribute

In connection to technological design Garud and Kumaraswamy (1995) identify three system-level attributes: integrity, modularity and upgradeability. As a systems attribute modularity can be used to describe any system. In that sense modularity is merely a matter of degree. In other words, every system is modular to some degree. In a recent, theoretical attempt to construct a causal systems model of the migration towards increasing or decreasing modularity Schilling (2000) defines the degree of modularity as the ability of a system's components to separate and recombine. This ability is, in turn, a result of the interaction between the system and forces in its context. Schilling (2000) identifies two such forces (in Figure 2-3): synergistic specificity and heterogeneity of inputs and demands.

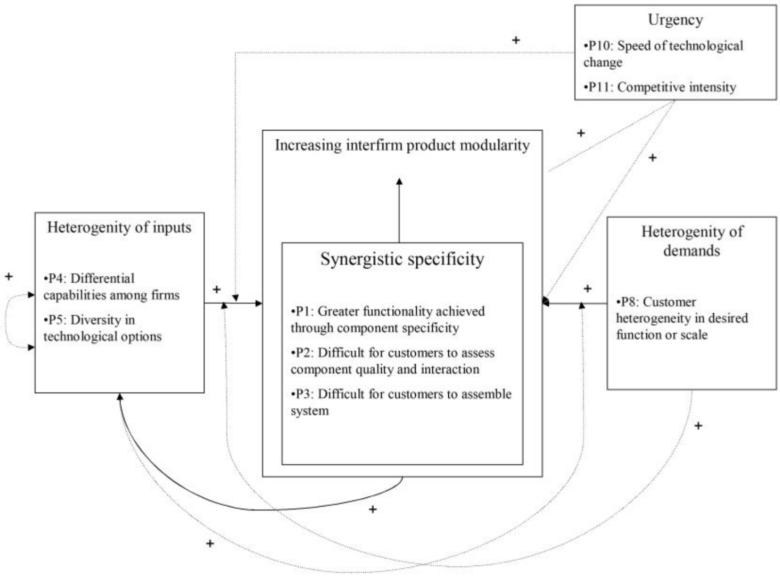


Figure 2-3 Factors influencing the migration toward/away from product modularity[1] (from Schilling, 2000: 321)

Schilling (2000: 316) refers to synergistic specificity as "the degree to which a system achieves greater functionality by its components being specific to one another". Ulrich expresses this in another, related and elegant fashion:

> *Local performance characteristics can be optimized through a modular architecture, but global performance characteristics can only be optimized through an integral architecture.* (Ulrich, 1995: 432)

---

[1] Solid lines represent direct and dashed indirect effects.

In fact, when such global performance characteristics are at the eye, the case of so called "function sharing" might be the most optimal design option (Ulrich and Seering, 1990), as opposed to a one-to-one mapping between functions and structures (Ulrich, 1995). That is, function sharing refers to the case when two functions share or are embedded in the same structure.

According to Schilling (2000) the heterogeneity of inputs and demands affect modularity in a positive way, i.e. the more heterogeneous the higher the degree of modularity. This is fairly natural given the way she defines the degree of modularity. If one, on the other hand, had looked at modularity from a (mass) customisation point-of-view, one would assume the opposite reaction. That is, the more heterogeneous the demand, the more viable completely customised designs would be, while a more homogeneous demand would allow for a higher degree of standardised components in the system.

Although I will adopt the 'systems' way of looking at modularity in this thesis, below I shall discuss all these forces from different perspectives by making use of a more common terminology. So, together with Miller and Elgård (1998), I see the drivers behind modularity to be: reduction of complexity, creation of variety and utilisation of similarities (commonalities); or in other words clarification, (mass) customisation and standardisation. Briefly speaking, almost all benefits of modularity can be derived from the independence-criterion used for managing complexity. Managing variety, i.e. balancing customisation and standardisation, stands out as a distinct category and will thus be discussed separately. Further, to give a more nuanced presentation of the advantages of modularity I will, in addition to these two categories, also distinguish between operational and strategic benefits.

2.2.2 Managing complexity

From a theoretical perspective modularity is best known as a means for handling complexity (for an overview, see e.g. Langlois, 2002). This idea dates back to the seminal works of Herbert Simon and Christopher Alexander. Their works were not explicitly concerned with modularity, but with the more general issues of "the architecture of complexity" and "the synthesis of form" respectively. Simon's connection to modularity resides in his works on complexity and the general arrangement of systems. The connection is especially apparent in his (1962) description of complex systems as "hierarchies of nearly decomposable (sub-)systems". A "complex system" he describes as "one made up of a large number of parts that interact in a non-simple way". According to Simon, most systems, artificial, social or organic, are made up of interacting sub-systems, which in turn can be divided into further lower level components and so forth, thus constituting a hierarchical whole. By "near decomposability" Simon refers to the situation when interactions between elements within the systems are stronger than the interaction between systems. Thus most systems can be decomposed into relatively independent sub-systems, which render the system as a whole more manageable. Contemporary with Simon, Alexander (1964) made similar conclusions in the more specific domain of architectural design. According to him good system design resides in the independency between sub-systems, or using Alexander's (1971: preface) own words, "diagrams" or more recently "patterns". In his own opinion, the main contribution of his early work (1964) was the "simple" idea that:

> *…it is possible to create such abstract relationships one at a time, and to create designs which are whole by fusing these relationships…* (Alexander, 1971: preface).

In a similar vein Nam Suh (1998) goes as far as to establishing a general theory for system design based his independence axiom. He thus seems to suggest that all systems ideally ought to be modular (by being independent). Ulrich (1995: 422) uses the concept of "de-coupled interfaces" to describe the independence feature in his definition of modularity above. He defines the term "coupled" with the following sentence:

> *Two components are coupled if a change to one component requires a change to the other component in order for the overall product to work correctly* (Ulrich, 1995: 423).

Ulrich (1995: 423) though states that in practical terms the interfaces between two physical components are almost always coupled to some extent, and that "coupling is relevant only to changes that modify the component in some useful way". In contrast to Alexander (1964) and Suh (1998), he moreover reminds us that modularity may not always be desirable (see the quote above, in the previous section). In other words, if a coupled interface is more useful than a de-coupled, the system design is likely to decline towards an integral architecture and vice versa. This again takes us back to Schillings (2000) system theoretical analysis in Figure 2-3.

Obviously complexity is a quite relative property of systems and may furthermore in practical terms be a too abstract a concept for describing the rationale behind modularity. Instead, regarded as a means for managing interdependencies and interfaces, technical or social, the idea of modularity appears clearer to most of us. In connection to this, Suh (1998) further states minimizing information content as another fundamental design axiom. This follows the notion of "information hiding"; a concept originally coined by David Parnas (1972: 1056), whose studies in the area of software programming directed our attention to the information needed to carry out the design work within modules. This clearly has implications for the organisational design of product development projects (Sanchez, 1995; Sanchez and Mahoney, 1996; Sosa et al., 2003; 2004), a topic that will be further explored in section 2.4 below.

2.2.3 Balancing standardisation and customisation

The success of 20th century industrial activity is undoubtedly at least partly a result of the conscious pursuit for economies of scale. The simple logic that the more you make of something, the cheaper you can make it, or differently put, the more standardised the things we make the cheaper they become (because we can make more of similar things), revolutionised industrial production. Henry Ford's moving production line and his famous statement that one can have any colour car as long as it is black have become symbols of this drive.

However, as man's wealth has prospered his taste has become more sophisticated. Not only does he want another colour car than black, but a whole range of other, more or less unique, features to satisfy his personal desires and needs. Man has of course always had personal tastes and requirements, but now she can also afford it. And producers have realised that competitive advantage not only resides in operational excellence and low cost production (Porter, 1996), but also in differentiation and more careful customer orientation.

Still not everything has to be unique. Lampel and Mintzberg express the central idea of this standpoint elegantly:

> *...customization and standardization do not define alternative models of strategic action but, rather, poles of a continuum of real-world strategies* (Lampel and Mintzberg, 1996: 21).

The idea is, on the one hand, to identify commonalities (Rutenberg, 1971) between product variants in a product family[1] and to embody them into modules, and on the other hand, to identify the need for variety and to embody these into alternative and interchangeable modules. An interface symmetry that allows for interchangeable building blocks has actually been among the most important characteristics found in the literature on modular systems, starting from the earliest ideas of 'modular' architectures in ancient Rome. Once identified the modules and their interfaces form the basis for a whole product family or, in other words, constitute a so called "product platform". Meyer and Lehnerd define this concept as…:

---

[1] Uzumeri and Sanderson (1995) define "product family" as "a set of (product) models that a given manufacturer makes and considers to be related".

> *...a set of subsystems and interfaces that form a common structure from which a stream of derivate products can be efficiently developed and produced* (Meyer and Lehnerd, 1997: 7).

As stated earlier the idea of creating variety through modular production was presented some 40 years ago (Starr, 1965). However, it was not until Stan Davis' (1987) book *Future Perfect* that the concept of mass-customisation was launched. The idea was popularised by Joseph Pine who furthered the concept through an influential book (Pine, 1992) and a series of co-authored *Harvard Business Review* articles in the 1990s (Pine, Victor and Boynton, 1993; Pine, Peppers and Rogers, 1995; Gilmore and Pine, 1997). The central idea has been the pursuit of meeting specific customer requests at near mass-production efficiency, or more explicitly defined: "delivering a service in response to a particular customer's needs, and (…) doing it in a cost-effective way" (Pine *et al.*, 1995: 105). Although mass customisation is often associated with the consumer market, Piller and Reichwald's (2002) description of combining fitting modules, whether they are internal operations or external suppliers, to a customer specific value chain is useful in the business-to-business-context.

Mass-customisation seems to be so similar to many other contemporary concepts, such as lean production, agile manufacturing and concurrent engineering, that a clear boundary cannot always be drawn between them. The subject has interested scholars across many disciplines, such as operations management, information systems, marketing, computer science and organisation theory (see e.g. MCPC, 2003). In practical terms, mass-customisation can be seen as the production strategy or business concept evolving from a flexible, modular product and process design. A modular design, in turn, enables the configuration of modules and processes into customer-unique deliveries, which as a whole constitute the basis for successful mass-customisation.

Lampel and Mintzberg (1996) also show how modularity can be used to balance the two opposite forces of standardisation and customisation along a continuum of choices. They introduce a categorisation of five strategies between the two extremes. Based on where in a four-step value chain (design-fabrication-assembly-distribution) the product becomes customised, they differ between: pure standardisation, segmented standardisation (customisation in the distribution process), customised standardisation (in the assembly process), tailored customisation (in fabrication) and pure customisation. Lampel and Mintzberg also identify three areas in industrial production that can be standardised or customised: the product itself, the working processes (based on which the categorisation above is made) and the transactions. Furthermore they classify industries along the standardisation and customisation continuum of these three areas. Thus we get: mass industries (everything standardised), thin industries (the opposite of the former), catalogue industries, menu industries, tailoring industries, routing industries, agent industries and bulk industries. Gilmore and Pine (1997) have developed another categorisation of approaches to customisation, largely based on the type of transaction or sales/service process: collaborative (customisation through dialogue), adaptive (customisable standard), cosmetic (standard product presented differently) and transparent (customisation not communicated). Duray, Ward, Milligan and Berry (2000), in their turn, provide us with an empirically validated typology based on differences in two dimensions: the point of customer involvement in the production cycle (design-fabrication-assembly-use) and the type of modularity employed (design-fabrication-assembly-use). They thus distinguish between: fabricators (design/fabrication - design/fabrication), involvers (design/fabricators - assembly/use), modularizers (assembly/use - design/fabricators) and assemblers (assembly/use - assembly/use).

A central concept in mass-customisation is “configuration”. Configuration as such can be seen as an engineering activity where certain configurations (‘constellations’) of a product or system are developed by choosing from a platform of more or less standard modules or building blocks (for a recent account see Riitahuhta and Pulkkinen, 2001). Rogoll and Piller (2003) describe a “configurator” as a tool with which a product/service is modelled to correspond to a specific customer’s needs, or in other words, a tool used for customizing product/service configurations. Although typically IT-based, the word “tool” is not entirely appropriate in every context as the configuration often is performed by a salesman/-department in collaboration with the customer (in engineering intensive industries, often with the help of the engineering department). Configurators can be seen as belonging to a larger group of computer aided selling (CAS) tools. These are tools for achieving customer integration, i.e. e.g. the idea of utilising the customer as a co-designer, as they enable fast visualisation and simulation of different product configurations. Customer integration can be seen as a development of the customer orientation paradigm, which undoubtedly is one of the strongest management paradigms of the past two decades. Seen from a broader perspective, one could even talk about economies of (customer) integration and economies of relationship (Piller and Möslein, 2002). Consequently companies are urged to design products (and product families) with the ease of configuration in mind (Riitahuhta and Pulkkinen, 2001).

2.2.4 Immediate, operative benefits of modularity

Admittedly, the division between operative and strategic benefits of modularity is not all clear cut. For comparison, Pahl and Beitz (1996) distinguish between user and producer benefits and provide us with a list of practical advantages of modularity (see Table 2-a). In a more general sense, the more immediate effects of modularity are discussed in this section, whereas the next section deals with longer term implications. I shall here focus on the three traditional dimensions of project management - time, cost and quality – in my discussion on operative benefits of modularity.

Table 2-a Advantages of modularity (from Pahl and Beitz, 1996: 447)

Advantages for the manufacturer:
Ready documentation is available for tenders, project planning and design; designing is done once and for all, though it may be more costly for that very reason.
Additional design effort is needed for unforeseeable orders only.
Combinations with non-modules are possible.
Overall scheduling is simplified and delivery dates may be improved.
The execution of orders by the design and production departments can be cut short through the production of modules in parallel; in addition parts can be supplied quickly. Computer-aided execution of orders is greatly facilitated.
Calculations are simplified.
Modules can be manufactured for stock with consequent savings.
More appropriate sub-division of assemblies ensures favourable assembly conditions.
Modular product technology can be applied at successive stages of product development, for example, in product planning, in the preparation of drawings and parts lists, in the purchase of raw materials and semi-finished materials, in the production of parts, in assembly work, and also in marketing.
Advantages for the user:
Short delivery times.
Better exchange possibilities and easier maintenance.
Better spare parts service.
Possible changes of functions and extensions of the range; and almost total elimination of failures thanks to well-developed products.

The cost driver is apparent in the paragraph on managing variety above. By utilising common parts firms may effectively optimise production and inventory in order to reduce costs (Rutenberg, 1971), although other factors such as the flexibility of the production process equipment influence the economics of producing variety (Ulrich, 1995). Money can indeed also be saved in product development itself. It is however often pointed out that a modular product typically is more difficult and costly to create than a corresponding integral one, whereas the benefits of a modular product are harvested later when new product variants are introduced.

Speed has become an increasingly important factor in product competition (Clark and Fujimoto, 1991; Clark and Wheelwright, 1993; Sanchez, 1995). As consequence much recent effort has been paid to reducing time-to-market in product development. Traditionally product development has followed a sequential process where one task is fully finished before the next begins. Through the idea of concurrent engineering firms gradually began to overlap tasks. A modular design, in contrast, enables through its standardised interfaces product development tasks to be carried out concurrently and autonomously (Sanchez and Mahoney, 1996). In Simon's (1962) famous watchmaker example, the type of watch that can be sub-assembled in parts ultimately is faster to produce because it can be finished in phases. In the industry this is often referred to as prefabrication of components and modules. The idea is that the preassemblies can be made concurrently at different factories and finally assembled at one place into a larger whole. Also the reuse of existing solutions speeds up development time and lowers development costs. Firms creating systemic products typically do not have to redesign the whole product but should focus on substituting some and keeping others, thus enabling a still faster product development process (Garud and Kumaraswamy, 1995).

Prefabrication also improves the quality of a product. Quality is indeed a tricky concept. In the sense of correct working (according to specifications) the power of modularity lies in the possibility to pre-test sub-systems prior to merging them into larger wholes. Thereby some mistakes can be avoided or more easily isolated and thus the quality of the overall product is improved. If we again see quality as a correlate to customer satisfaction, the idea is of course to be able to offer customised but reliable and affordable products. It is however easy to realise that a good trade off might be very difficult to achieve.

2.2.5 General, strategic implications of modularity

Together with increased customer orientation, product development and the ability to innovate has emerged on the strategic management arena. Also, as many product markets have become more dynamic the pattern of product competition has changed. Sanchez (1995) lists advancements in manufacturing and design related IT and modular product design both as driving forces behind these changes in product markets and as enablers for the strategic flexibility needed to compete in such markets; the more flexible the product the greater the strategic flexibility. Sanchez (1999) has later emphasised the significance of modular product architectures in the marketing process, including the creation and realisation of new products. He lists the intensive segmentation of consumer tastes as one of the most important implications of modularity for the marketing function in the firm. Just as a modular system can be designed separately from other systems, a modular system provides an opportunity for fine-tuning the product to match consumer taste (Langlois and Robertson, 1992) and thus engage in "real-time market research" and more effectively target specified market segments (Sanchez, 1995). Such an approach requires high model variety and carefully constructed product families that further enables rapid product proliferation and performance improvement (Sanchez, 1995; Sanderson and Uzumeri, 1995; Uzumeri and Sanderson, 1995). Garud and Kumaraswamy (1995) argue that in addition to speed, future competition will require the ability to integrate ever more systemic products. According to them such demand will urge companies to create technological systems that are easily upgradeable and thus have the potential to yield what they term "economies of substitution". They use the term "substitution" to indicate that technological progress in systemic products can be achieved through substituting only some of the components or systems of the product while reusing others. In a commentary to their article they even speculate that economies of substitution will be important for our understanding of the future 21st century industrial landscape in the same way as the theories of economies of scale and scope have improved our understanding of industry structures in the 20th century (Garud and Kumaraswamy, 2003). Grabher (2004) uses a similar concept, "economies of recombination", when dealing with the balance between project specific solutions and the reuse of knowledge modules from earlier projects. According to him, "economies of recombination" accrue from "the creation of novel combinations of familiar elements and by-products from previous projects" (Grabher, 2004: 1497).

Also the relationship between modularity and innovation has been examined. Langlois and Robertson (1992) show how the evolution of micro computer and high-fidelity stereo industries has migrated towards modular systems. As these products can easily be split into separate subsystems the evolution has favoured a networked industry structure rather than big, vertically integrated enterprises. Baldwin and Clark (1997) expect modularity to boost innovation as specialised suppliers assume responsibility for the development, design and production of modules.

2.2.6 Disadvantages and dangers of modularity

However, modularity is not all good and does not come without trade-offs. Above I already mentioned the trade-off between local and global performance characteristics (Ulrich, 1995), or using Schilling's (2000: 316) wording, the issue of "synergistic specificity".

Baldwin and Clark (1997: 90) argue that architect managers needed in this new, modular way of organising business "will have to become much more attuned to all sorts of developments in the design of their products"; they still have to be knowledgeable of the development of the industry as a whole. According to Fleming and Sorenson, here lies one of the greatest dangers with modularity:

> *Our findings call into question the trend at many companies toward highly modular designs. Although such designs make product development more predictable, many companies appear to use modularization techniques to the point where they undermine the innovation process by reducing the opportunities for breakthrough advances. Moreover, the predictability inherent in modular approaches raises the odds that competitors will develop similar products.* (Fleming and Sorenson, 2001: 21).

Fleming and Sorenson (2001) have furthermore found indications that intermediate levels of interdependence between components produce the most useful inventions. They also recommend a contingent approach to modularity, i.e. an approach that depends on the specific industry or business context.

In line with their listing of demand and supply side benefits of modularity (Table 2-a above) also Pahl and Beitz (1996) list some practical disadvantages of modularity, as shown in Table 2-b.

Table 2-b Disadvantages of modularity (from Pahl and Beitz, 1996: 447-448)

Disadvantages/limitations for the manufacturer:
Adaptations to special customer's wishes are not as easily made as they are with individual designs (loss of flexibility and market orientation).
Once the system has been adopted, working drawings are made on receipt of orders only, with the result that the stock of drawings may be inadequate.
Product changes can only be considered at long intervals because once-and-for-all development costs are high.
The technical features and overall shape are more strongly influenced by the design of modules and the modularity than they would be by individual designs.
Production costs are increased, for example, because of the need for accurate locating surfaces; production quality must be higher because re-machining is impossible.
Increased assembly effort and care are required. Since the user's as well as the producer's interests have to be taken into consideration, the determination of an optimal modular system may prove very difficult.
Rare combinations needed to implement unusual requirements may prove much costlier than tailor-made designs.
Disadvantages for the user:
Special wishes cannot be met easily.
Certain quality characteristics may be less satisfactory than they would be with special-purpose designs.
Weights and structural volumes of modular products are usually greater than those of specially designed products, and so space requirements and foundation costs may increase.

2.2.7 Technology dynamics and dominant designs

Obviously there is a great number of different drivers for (and against) modularity. Let us finally see how modularity relates to the dynamics of technology at large, in order to get more perspective on the issue at hand.

The evolution of technological systems has received much scholarly attention. A topic of special interest has been the origins of so called "dominant product designs", pioneered by Utterback and Abernathy (1975). They describe a dominant design as a best compromise of existing innovations; a sort of design standard that triggers changes in the manufacturing process enabling more standardized production.

Missing a more social, evolutionary interpretation of the phenomenon, Anderson and Tushman (1990) engaged in a search for a cyclical model of dominant designs and incorporated the concept with their idea of "technological discontinuities" (Tushman and Anderson, 1986). As a result they define a "dominant design" as the fermented design that usher in an era of incremental change, which in turn is broken by subsequent technological discontinuities. Rather than seeing a dominant design as a single best techno-economical optimum, they describe the process of reaching a dominant design as a socio-political and organizational phenomenon moderated, rather than determined, by economical and technical constraints. Consequently, dominant designs lag behind an industry's technical frontier, and furthermore, can only be known in retrospect (Anderson and Tushman, 1990).

The above mentioned works employ a unit of analysis comprising the product. So do Henderson and Clark (1990), but specifically turn our attention to the linkages between components in a product. On the suggestion of Michael Tushman they introduce the concept of "architectural innovation", which is used to denote changes in how components within a product connect. This significantly extends our traditional, dichotomous understanding of radical and incremental innovation. Henderson and Clark (1990) suggest that changes to dominant designs can be compared with radical changes to both product architecture and components.

In an attempt to synthesise the ideas of dominant designs, technological discontinuities and architectural innovation Tushman and Murmann (1998) formulate a set of hypotheses regarding both technical settlements and organisational outcomes. These partly build on a distinction, after Clark's (1985) insight that not all subsystems are of equal importance, between core and peripheral subsystems. Consequently they see products as "nested hierarchies of core and peripheral components, each of which has its own technology cycles" (Westerman and Tushman, 2003: 348). Quite naturally the hypotheses differ depending on whether the unit of analysis is at the product or subsystem and linkage level, and then for the latter case, whether we consider core or peripheral subsystems. This makes Tushman and Murmann (1998; 2003: 335) redefine the concept of "dominant design" as occurring in a situation "when all core subsystems are in eras of incremental change". Thus they also seem to suggest that there may be vast implications of the fact that different subsystems are in different phases of their technology cycles. Brusoni *et al.* (2001) have explored this idea further and show us that it is in order to cope with such uneven rates of development in employed technologies and with unpredictable product-level interdependencies that multitechnology firms need to retain knowledge about more than they make themselves.

Furthermore, with specific respect to complex and low volume products Tushman and Murmann make the following observations:

- *The more complex the product, the greater the centrality of linking mechanisms* (Tushman and Murmann, 1998; 2003: 332).
- *For complex products, core subsystems will shift over time* (Tushman and Murmann, 1998; 2003: 332).
- *For complex products, subsystem and linking dominant designs emerge out of social/political processes between communities of interest* (Tushman and Murmann, 1998; 2003: 333).
- *Dominant designs will either not emerge in regulated or low-volume markets or will be locally idiosyncratic* (Tushman and Murmann, 1998; 2003: 333).

Although not explicitly concerned with dominant designs, Chesbrough (2003) makes similar arguments as Tushman and colleagues and maintains that modularity is not an end-state of technological evolution, since all architectures contain performance limits. Thus he predicts that technological evolution will cause architectures to move between integrated and modular (distributed) depending on the maturity of the technology in question. This would also for its part explain why, as Brusoni *et al.* (2001) argue, some firms need "know more than they make". Otherwise they run the risk of being caught in a "modularity trap" (Chesbrough and Kusnoki, 2001).

2.3 Principles and methods for modularisation

> *First, the taking in of scattered particulars under one Idea, so that everyone understands what is being talked about…Second, the separation of the Idea into parts, by dividing it at the joints, as nature directs, not breaking any limb in half as a bad carver might.*
>
> Plato, *Phaedrus*[1]

> *How complex or simple a structure is depends critically upon the way in which we describe it.*
>
> (Simon, 1962; 2003: 34)

2.3.1 General approaches to modularisation

Management literature is full of accounts of why modularity is good, but mostly takes modularity for granted. However, when it comes to telling us how to actually achieve it that literature is less useful. The literature in engineering design (and software engineering) comes closer to our needs in this respect. However, like in management literature modularity has become a major topic in design literature only in the 1990s, although the roots of modularity date from much earlier. Before the mid 1990s the accounts on modularity appear to be, as Ulrich (2003: 147) puts it, "largely heuristic and anecdotal", although some works of a more 'scientific character' have appeared (Rutenberg, 1971; Steward, 1981). These were however not concerned with modularity *per se* or widely applied, and merely considered some limited aspect of modularity. Not very surprisingly, given its long history, among practitioners product architecting also appears to be a most heuristic activity (Stone, 2000; Dahmus *et al.*, 2001; Ulrich, 2003). In search for a more systematic modularisation process, the engineering design literature nowadays provides us with a plethora of different principles, methods and metrics for the creation of modular products and product platforms. Some aim to provide precise metrics for the modularisation process, whereas others offer a combination of quantitative modelling and qualitative heuristics. As the purpose of this section is merely to give a brief overview of some widely cited principles for modular product structuring, I refer to Blackenfelt (2001a) for an extensive review of modularisation methods.

Design theory typically describes the design process as departing from a "need" or a "problem" to which a technical solution has to be found by moving through a subsequent set of design domains (Hubka and Eder, 1988; Pahl and Beitz, 1996; Suh,

---

[1] From Alexander (1963).

1998). Suh (1998) advocates four such domains: the customer, functional, physical and process domain. Pahl's and Beitz' (1996) widely cited sequential model for engineering design also consists of four main phases: task clarification, concept design, embodiment design and detailed design. According to them, modular product development proceeds along a similar path. The basis for this path should explicitly be the function structure (see Figure 2-1). Following a similar line of thought Blackenfelt (2001a) distinguishes between modularisation of the product structure and detailed module design. Blackenfelt (2001b) furthermore makes a related distinction between strategic and functional aspects in the module creation process. These are, in essence, the categories in which most modularisation approaches can be divided. On the one hand, modularisation is seen to stem from the product architecture or function structure, so that functional elements then should be made fairly independent, thus reducing complexity (Pimmler and Eppinger, 1994; Ulrich, 1995; Pahl and Beitz, 1996; Sosa et al., 2003). On the other, modularisation might pay off well when used as a means for managing variety and pursuing economies of scale by creating a product family platform with common parts for different product variants (Erixon, 1998; Robertson and Ulrich, 1998; Muffatto and Roveda, 2000).

Two of the modularisation approaches, representing each of the above two types, which have received perhaps most attention, make use of relational matrices: (1) the "design structure matrix" (Steward, 1981; Pimmler and Eppinger, 1994) and (2) the "modular function deployment", which entails the use the "module identification matrix" (Erixon, 1998). Below I will present these two methods in more detail. In addition, another influential concept, namely "information hiding" (Parnas, 1972: 1056) will be discussed as well as life-cycle engineering approaches used in modularisation.

2.3.2 The use of Design Structure Matrix for product structuring

The design structure matrix (DSM) was first invented in the 1980s by Steward (1981). However, it was not until the 1990s that it received more attention through the work of Steven Eppinger and his colleagues at MIT. As a systems modelling tool it is particularly useful for representing and investigating the relationships between elements in systems. It can basically be used for two different things: (1) for clustering interacting elements of a system into larger 'modules' based on their physical interaction, and/or for sequencing the tasks of a project according to its information structure. Both applications are of interest for this thesis, the former with regards to the topic of this chapter, and the latter when it comes to the organisation of projects and project business, and for the specific application of structuring organisations according to the modularity principle (Sosa *et al.*, 2003), a topic that will be reviewed in section 2.4. Section 3.2.3 will describe how the technique is applied in practice.

The DSM has clearly shown its usefulness as a systems modelling tool. However, it does not explicitly consider the variability aspects in modularisation, which thus have to be addressed implicitly when analysing the matrix. The same goes for other strategic and organisational aspects.

2.3.3 Erixon's Modular Function Deployment

Erixon's (1998) work on technical and rational criteria for the development of modular products, resulting in a method he calls Modular Function Deployment (MFD), serves as a good summary of the framework developed so far. The MFD consists of five major steps:

1) clarification of customer requirements
2) selection of technical solutions
3) generation of concepts
4) evaluation of concepts
5) improving the module

As such it resembles Pahl's and Beitz' (1996) classical model for engineering design. More precisely, it builds on the "Quality Function Deployment" (QFD), which is used in step 1. Step 2, in turn includes a functional analysis, but does not provide or assign a particular tool for doing it. In step 3 the "Module Identification Matrix" is deployed in order to combine the results from steps 1 and 2 are combined and assessed together with other "module drivers". The drivers actually cover many of the aspects discussed in this chapter. These aspects can roughly be divided into three major groups: those indicating the variability needs and commonality opportunities, those building on life-cycle engineering principles, and those taking into account strategic issues such as technology evolution and supplier availability.

As we can see the MFD addresses both major aspects of modularity, i.e. managing variety and complexity. It appears to be clearly stronger on the variety and commonality aspects, though, and puts less emphasis on functional modelling as a basis for modularisation. Thus it is likely to be less appropriate for analysing big, systemic capital goods, at least in comparison with the DSM-method presented above. However, the MFD appears to be widely and successfully applied on smaller consumer and industrial goods (Ericsson and Erixon, 1999).

2.3.4 The concept of "Information hiding"

Parnas' (1972) studies in the area of software programming have become influential for our understanding of complexity within technical systems. Among others he is the inventor of the notion of "information hiding". He drew attention to the "real" interdependencies between modules, i.e. to the information needed to carry out a certain design task. By minimising these interdependencies the work on each module could be done quite independently of each other; i.e. the information needed to carry out the works within one module were "hidden" from those working outside that module. In a similar vein Suh (1998) further states minimizing information content as another fundamental axiom in his general theory for systems design.

Baldwin and Clark (1997) have also continued this line of thought. Drawing upon extensive research in the computer industry they have attempted to formulate a general set of principles of modular systems design. First of all they distinguish between "visible design rules" and "hidden design parameters". They continue by claiming that "modularization is beneficial only if the partition is precise, unambiguous and complete". Baldwin and Clark (1997) further divide the visible design parameters into: an architecture, interface descriptions and test standards. They maintain their absolute view that hidden design parameters "are decisions that do not affect the design beyond the local module".

2.3.5 Life-cycle engineering aspects of modularity

During the past two decades concurrent and/or life-cycle engineering[1] has become an important issue for many manufacturing companies (see e.g. Kusiak, 1993; Molina, Sanchez and Kusiak, 1998). In literature the concepts are often used more or less interchangeably (Kusiak, 1993). Kusiak defines the concepts as follows:

> *Concurrent engineering the practice of incorporating various values of a product into the design at its early stages of development* (Kusiak, 1993: ix).

> *Life-cycle design means that all life-cycle phases of a product (i.e., development, production, distribution, usage and disposal/recycling) are considered simultaneously from the conceptual stage through the detailed design phase* (Kusiak, 1993: ix).

In essence, modules are not that different from products at large, despite the fact that they are an independent part of a larger whole (product). Consequently the same life cycle engineering principles become important for companies that pursue a

---

[1] In the literature the concepts of concurrent engineering and life-cycle engineering are often used more or less interchangeably.

modular design strategy. Namely, the functionality requirements in different phases of the life-cycle of a product are likely to have implications for decision concerning the product architecture, as is the case in the MFD discussed above. Ishii's (1998) discussion on life-cycle modularity metrics can be summarised in four perspectives on functionality of modules:

- End user perspective (level of modularity and required flexibility)
- Manufacturing perspective (e.g. commonality and Design-For-Assembly methodologies)
- Service perspective (serviceability and reliability)
- Recyclability perspective

Ishii's (1998) approach to modularisation with charts showing each of the above four aspects is not very different from Erixon's (1998), apart from the fact that he directs more focus to the later part of the module/product life cycle. However, rather than merely providing metrics for modularisation in a complex life cycle context Ishii (1998) regards modularity as means for coping with these complexities, that is, as a means for life cycle engineering, a view he shares with Gu and Sosale (1999). Such an approach, however, seem to look for one single decomposition that holds in all phases. Whereas this might be feasible in general, for more complex products it certainly is not obvious. Quoting Sako:

> *Any product has to be designed, produced and used by explicitly recognizing the hierarchy of components and functions. But different phases of the product life cycle demand different objectives, and the need to coordinate between them imposes another layer of complication in attempting a single optimal decomposition of products.* (Sako, 2003: 232).

Commonly the following distinctions are made with respect to modularity in different stages of the life cycle (or with respect to different organisational functions): "modularity in design" (Baldwin and Clark, 1997: 85), "modularity in production" (Baldwin and Clark, 2000: 78) and "modularity in use" (Baldwin and Clark, 1997: 86). Modularity in design (MID) corresponds mainly to the independence and specified interface criteria articulated in the definitions in section 2.1.2. Consequently it can also be perceived as a kind of "modularity in product architecture" (Sako, 2003: 230). Modularity in production (MIP), in turn, refers to the old manufacturing practice of simplifying complex production processes by dividing them into modular processes or sub-/preassemblies (Baldwin and Clark, 1997). Finally, modularity in use comes close to the idea of mass-customisation, as it expresses the idea that customers may mix and match elements (modules) into different product configurations according to individual taste and needs. For industrial goods the term 'modularity in operation' might be more appropriate, reflecting the need to take into account reliability, serviceability and, for instance, upgradeability issues. The distinction between MID, MIP and MIU could partly be seen as a further abstraction of Ishii's (1998) four perspectives above. Some authors even suggest, in accordance with Sako's (2003) notion of the difficulty "in finding one single optimal decomposition", that modularity and products best be managed as "interlinked multiple hierarchies" (Takeishi and Fujimoto, 2003; cf. Hameri and Nitter, 2002). These ideas in relation to organisational design will be discussed in section 2.4.2 below.

2.4 Modularity and organisational outcomes

2.4.1 Modularity in organisation

Garud and Kumaraswamy (1995) argue that firms not only need to design technological systems that can yield economies of substitution, but also create organisations that can realise such economies. The idea builds on Simon's (1962) notion that not only complex, artificial systems are composed in a hierarchical manner, but also social systems such as organisations. Sanchez and Mahoney (1996: 64-66) describe how standardised product interfaces create a well-defined "information structure" that specifies how the components of a product function together and consequently how the corresponding development processes and groups connect; in essence, "products design organizations". Although this admittedly often can be the other way around (Sako, 2003; Takeishi and Fujimoto, 2003) as is discussed in the next two sections, it still is a conceptually powerful notion, rather than merely 'a rational dream'.

The notion of modular organisations thus touches upon the concept of "loosely coupled systems", a dialectical concept used in attempts to mediate the organisational contradiction between connection and autonomy (Orton and Weick, 1990). According to Garud and Kumaraswamy (1995) modularity implies breaking and managing many old dichotomies such as incremental versus radical change, market versus hierarchy, competition versus co-operation, and craft versus mass production. Modularity in organisation lies at the heart of the market-hierarchy contradiction. Sanchez and Mahoney (1996) explain this as the case when a well-defined information structure enables a kind of "embedded coordination without the need to continually exercise authority". Later Langlois (2003) has even made reference to "the vanishing hand" of modularity. That is, as interfaces become fully standardised and specified, neither market nor hierarchy is needed to coordinate the transactions within an industry. To what extent this is fully applicable in practice is, however, not entirely clear (Langlois, 2002). Moreover, we have to distinguish between modularity in organisation and modularity in market. Although the personal computer industry may provide a perfect example of the case when modularity in product design leads to modularity in market, this is not the case in many other industries (Chesbrough, 2003). For instance, the evolution of modularity in the automotive industry has taken quite different paths when it comes to modularity in organisation (Takeishi and Fujimoto, 2003), but in essence remain 'closed' rather than 'open' when it comes to the market. Thus we cannot see the same 'mixing and matching' between modules as in the PC industry (Sako, 2003).

Modularity in organisation also has certain implications for practice. As Sanchez and Mahoney (1996) contend modularity in product design forms a basis for knowledge management and organisational learning. First of all, it separates the architectural knowledge from the component knowledge. Thus it renders the learning environment less complex and enables the component development processes to be executed in parallel as discussed earlier. This could then for instance be used to trace "capability bottlenecks" in the organisation (Sanchez and Collins, 2001).

2.4.2 Firm and task interfaces

Sosa *et al.* (2003) show another practical dimension of decoupling architectural and component knowledge when they distinguish between "modular and integrative systems". They define "modular systems" as "those whose design interfaces with other systems are clustered among a few physically adjacent systems", i.e. systems that are de-coupled, and "integrative systems", in turn, as "those whose interfaces are physically distributed or functionally integrative across all or most other systems" (Sosa *et al.*, 2003: 240). This has important practical implications for managing technical team interaction in product development, or what McCord and Eppinger (1993: 4) term "the integration problem of concurrent engineering". For instance, one might choose to assign special integration teams (McCord and Eppinger, 1993), or integrative design teams (Sosa et al., 2003), for integrative systems, or even let the more independent (modular) teams overlap in order to address the systems engineering needs (Pimmler and Eppinger, 1994). Modular and integrative systems can be identified e.g. with the help of the design structure matrix presented above (Sosa et al., 2003).

In essence, product/task interdependence plays a central part in the issue of vertical integration (Walker and Weber, 1984; Dyer, 1996) or in organising and organisational design in general. Interdepartmental task dependence and coordination mechanisms have been on the research agenda at least since the seminal works of Galbraith (1973) and Thompson (1967). Such interdependencies are indeed a result of how the task at hand partitioned into sub-tasks. Thus "task partitioning" becomes an innovation process variable that actively can be managed as shown by von Hippel (1990). He proposes two ways in which this can be done: 1) adjustment of the task specification and 2) reduction of the barriers to interaction. As seen above product interdependencies with fairly good accuracy translate into design team interaction thus providing a structured basis for managing product development processes (Pimmler and Eppinger, 1994; Sosa et al., 2003; 2004).

The DSM-based approach draws on both above mentioned strategies for handling interdependencies, that is: 1) by adjusting the system boundaries in order to reduce interdependencies (and increase modularity) and 2) by incorporating integration or integrative teams to handle cross boarder interdependencies. However, it merely applies to the design of products and the situation becomes more complicated when taking into account other phases of the product life cycle. Following von Hippel (1990: 414-415), let us consider the design and manufacture of two components A and B, of which at least B is sourced from outside. Clearly, there is both a product/design interface between A and B and an organisational interface between design and manufacture of component B. Let us now furthermore focus on the second strategy for managing these interdependencies. It will give us two possibilities: either one can decide to partition the whole task at the product interface or at the organisational interface thus allowing the manufacturer of component B to take care of the design itself. Which strategy is better of course depends on the case. In general, it is often suggested that design done by suppliers comes with clear benefits (Clark, 1989), which is natural to think as the supplier then more freely can adopt a design for manufacturing thinking. However, for a very integrated product it might be equally wise to reduce the communication barriers between the design teams of the components of such a product (von Hippel, 1990).

Partitioning at the organisational interfaces, largely assumes a perfect match between product and organisation, which as already said is not always the case. In his article on the design-manufacturing/build interface Adler (1995) draws our attention to the temporal dimension of projects that according to him earlier works have overlooked. He suggests that the interdependencies vary in strength and type through the course of a project. His arguments are in line with Sako's (2003) quote above in section 2.3.5, which further extends the view of the module life cycle. In addition to the distinctions made with respect to the module life cycle, i.e. modularity in design (MID), production (MIP) and use (MIU) (see section 2.3.5), one can furthermore specifically refer to 'modularity in organisation' (or in Takeishi and Fujimoto's (2003) words "modularity in inter-firm system") as seen above. As said in Sako's quote, all these views on modularity might have different objectives and can thereby be described as “interlinked multiple hierarchies” (Takeishi and Fujimoto, 2003). Interfaces are after all but one, although very important, issue in modularisation. Thus we also realise that the prescription that ‘products design organisations’ have to be considered with some caution. First, organisational interfaces are much more difficult to specify than technical interfaces. Second, it might even be so that the existing organisation and its capability distribution determine the product architecture rather than the other way around. (Sako, 2003). Next I will examine other objectives for modularity and in particular how they relate modularity in organisation or outsourcing in general.

2.4.3 Modularity and outsourcing

In some industries, notably the automotive, the conception of ‘modularity in organisation’ has become a synonym to outsourcing. It is, however, far from obvious that modularity in product architecture automatically leads to outsourcing. For instance, it seems that Japanese auto manufacturers have started from an emphasis on production system modularity and then gradually moved towards considering modularity in product architectures and organisation, whereas European counterparts typically have focused on outsourcing component manufacturing (modularity in organisation and production) and only then considered modularity in product architectures/design (Takeishi and Fujimoto, 2003). This is commonly considered to be a result of the fact that Japanese firms in general are more integrated or work in a more integrated manner than Western firms (see e.g. Dyer, 1996; Sako, 2003). Although such generalisations have to be taken with some caution, it clearly shows us that the way to ‘go modular’ may follow one of several paths. The same can be realised if considering the differences in the drivers for modularity between the automotive and the computer industry (see Table 2-c).

Table 2-c Modularity in computers and autos compared (from Sako, 2003: 249)

	Computers	Automobiles
Catalyst for modularity	MIU → MID	MIP → MID
Organisational adaptation	Modular design teams and start-ups first, outsourcing later	Outsourcing, tiering and consolidation of suppliers
Labour markets	Mobility of technical labour	Wage differentials between OEM and suppliers
Capital markets	Venture capital for start-ups	Investment banking advice for M&A

Clearly, neither marketing (mass customisation) nor production (sub-assembly) or technology strategy choices imply a direct link from product modularity to outsourcing. In fact, for the latter one could even argue for the contrary (Brusoni *et al.*, 2001). However, according to Sako (2003) financial strategy (see Table 2-c) is the only decision that is directly concerned with outsourcing modules, although outsourcing itself does not necessarily require product modularity. Managing complexity via consolidation of suppliers is often mentioned as a driver towards organisational modularity, although it is fair to say that the benefits might be difficult to assess in that case. The same goes for the expected boost in innovation through modularity in organisation (Langlois and Robertson, 1992; Baldwin and Clark, 1997). Complexity management goes hand in hand with responsibility allocation. An interesting example here is the concept of "modular consortia" applied at VWs truck factory in Resende, Brazil, where each module supplier assumes responsibility for the delivery all the way to on-line assembly at VWs factory. In addition, for each car failing the quality test the error is traced back to the corresponding supplier who has to reimburse the costs caused by the failed vehicle to all other involved parties. (Collins *et al.*, 1997; Marx *et al.*, 1997).

The nature of project business

The business of creating ships, power stations, telecom networks, paper machines etc indeed differs from the business of developing and producing mobile phones, automobiles, hand tools and the like. Part of the motivation for this thesis lies in this difference. As an analytical category the latter have received more attention. In this part of the literature review my aim is to by use of existing literature discuss the supposedly different characteristics of the former.

2.5 What is project business[1]

2.5.1 Related concepts

There are many concepts that are related to or used for denoting what I here refer to as "project business":

- Project-oriented organisation (Turner, 1992)
- (Global) Project Business (Artto *et al.*, 1998)
- Project-based industry (Wikström, 2000)
- Project-based organisation (Hobday, 1998; 2000)
- Project-based company (Lindkvist, 2001)
- Project-based firm (Keegan and Turner, 2002)

Or specifically regarding the product of such business(es):

- Large Technical System (Hughes, 1983)
- Complex Systems (Miller *et al.*, 1995)
- Complex Product System (Hobday, 1998)

All these concepts are likely to be relevant for my study in some aspect. I will however not here dwell on the differences between these concepts, but restrict myself

---

[1] The heading is adopted from Artto and Wikström's (2005) recent editorial in the IJPM.

to state that my interest here is "project business" understood as the whole business around the delivery of large, systemic/complex capital goods[1]. Below I will touch upon some of the above concepts that are central the theoretical framework in this thesis. As this thesis is concerned with the delivery chain, which traditionally would be studied under the operations management label, I will start the discussion on project business in that discipline.

2.5.2 From project management to project business

Uniqueness is a common element of some of the most cited definitions of projects (Turner, 1992; PMI Standards Committee, 2000), and undoubtedly one of the most distinguishing features of projects. Literature in the operations management-field seldom points out this fundamental difference, or other distinguishing characteristics, between mass-production and projects, but rather makes the difference by presenting the special planning and controlling techniques developed for project management (see e.g. Buffa and Sarin, 1987; Chase and Aquilano, 1992). While such tools and techniques might have helped us a lot in logically shaping projects, their shortcomings have become apparent. Although the emphasis within the operations management discipline in large has moved towards more holistic concepts like operations strategy quite the same has not happened in project management-studies (Maylor, 2001). However, during the past decade some streams of literature have come to suggest new vistas for research on projects (e.g. Lundin and Söderholm, 1995; Packendorff, 1995; Artto *et al.*, 1998; Gann and Salter, 2000; Wikström, 2000; Engwall, 2003; Skaates and Tikkanen, 2003; Brady, Davies and Gann, 2005). For instance, Artto *et al.* (1998: 17-32) call for a shift in focus "from project management to project business[2]", emphasising the link between project processes and ordinary business processes in a company (see also Gann and Salter, 2000). In a review of recent contributions in the field of project management Söderlund (2004) has found some implications for a movement from "project management research" towards "project research". However, according to his study it still seems like most of the contributions are devoted to issues around the single project and less attention is given to multi-project contexts, an issue central to the idea of a distinguishing type of business analysed in this thesis. Namely, in the multi-project context the uniqueness of a project can indeed be questioned (Kadefors, 1995; Blomberg, 1998). Clearly, most projects contain both tasks that are unique and tasks that are somehow repetitive (Lundin and Söderholm, 1995). This has important implications for the management of a business where projects are the main mode of production.

---

[1] I want to thank Andy Davies for helping to see the difference between the "project-based" and "project business".

[2] Artto et al. (1998) defines project business as: "the activities of a company – a project company – that carries out and delivers projects for its customers".

On the other hand, Artto and Wikström (2005), based on a large bibliometric study on the sources and occurrence of project business related content, note that the analysed journals do not see "projects as manufacturing vehicles in a firm's production line", and, that there are few sources explicitly addressing the strategic importance of projects. As for the former, they admit that such content is likely to be present in more operatively-minded journals omitted in their study. Inspired by the theory of the firm and underlining the strategy-point-of-view Artto and Wikström put forward the following definition:

> *Project business is the part of business that relates directly or indirectly to projects, with a purpose to achieve objectives of a firm or several firms* (Artto and Wikström, 2005: 351).

Indeed, seen as a business, differences, perhaps more fundamental, between mass-production and project business can be found in other areas than operations (and project) management: for example, in organisation theory and the logics of value creation, in marketing, in innovation and product characteristics, and consequently in strategy. These are the topics that I will discuss in the next few sections, while keeping in mind that this thesis deals with projects that are both "unique and repetitive" (Lundin and Söderholm, 1995: 441).

2.5.3 Elements of project business: the CoPS-framework

The discussion below is based on Mike Hobday's (1998) framework on differences between the creation of complex products and systems (CoPS) and mass production. He holds that CoPS are an overlooked analytical category, especially in terms of innovation studies. In Table 2-d he lists some characteristics of CoPS in contrast to mass production industries.

Table 2-d CoPS versus mass-production (Hobday, 1998: 699)

	CoPS Project organisation	Commodity products, Functional organisation
Product characteristics	Complex component interfaces Multi-functional High unit cost Product cycles last decades Many skill/knowledge inputs (Many) tailored components Upstream capital goods Hierarchical/systemic	Simple interfaces Single function Low unit cost Short product life cycles Fewer skill/knowledge inputs Standardised components Downstream consumer goods Simple architectures
Production characteristics	Project/small batch Systems integration Scale-intensive, mass production not relevant	High volume/large batch Design for manufacture Incremental processes, cost control central
Innovation processes	User-producer driven Highly flexible, craft based Innovation and diffusion collapsed Innovation paths agreed ex-ante among suppliers, users etc. People embodied knowledge	Supplier-driven Formalised, codified Innovation and diffusion separate Innovation path mediated by market selection Machinery embodied know how
Competitive strategies and innovation coordination	Focus on product design & development Organic Systems integration competencies Management of multi-firm alliances in temporary projects	Focus on economies of scale/cost minimisation Volume production competencies (e.g. lean production, TQM, MRP)
Industrial coordination & evolution	Elaborate networks Temporary, project-based multi-firm alliances for innovation and production Long-term stability at integrator level	Large firm/supply chain Single firm as mass producer Alliances usually for R&D or asset exchange Dominant design signals industry shake-out
Market characteristics	Duopolistic structure Few large transactions Business to business Administered markets Institutionalised/politicised Heavily regulated/controlled Negotiated prices Partially contested	Many buyers and sellers Large numbers of transactions Business to consumer Regular market mechanisms Traded Minimal regulation Market prices Highly competitive

CoPS indeed constitute a special (extreme) domain of capital goods and admittedly differ from more common forms of projects on certain points. One could say that it resembles the large-scale, one-off projects that lie behind much of the development of common project management tools and techniques. It will though serve as a useful frame for analysing the kind of projects that my study is concerned with. And although "the mass production vs. CoPS contrast is over-simplistic", as Hobday (1998: 707) himself notes, it aligns the poles of a continuum of characteristics, however not necessarily linear or one-dimensional. While Table 2-d is clear and self-explanatory, the next shall not be a replication of it, but rather a discussion incorporating other streams of literature in order to shed some light on the continuum. I will later on in chapter 4 position my cases in relation to the framework. However, as the different characteristic types are overlapping and interdependent this chapter should as well be regarded as a whole, rather than a strict analysis of the parts of project business.

2.6 Product complexity and the management of technology

Large, engineering-intensive capital goods are often credited with the attribute of complexity. Such technical complexity is typically seen to stem from the uncertainty in the interfaces between the many sub-systems that are integrated into one larger system, which in turn create great interdependency, both technically and in an organisational sense. (See e.g. Miller *et al.*, 1995; Bonaccorsi *et al.*, 1996; Eppinger, 1997; Hobday, 1998; Sosa *et al.*, 2003) This uncertainty resides in both technological novelty, i.e. lack of scientific understanding, and unique and emerging customer requests, which in turn may result in a high degree of tailored components (Bonaccorsi *et al.*, 1996; Hobday, 1998). One of Hobday's (1998) conclusions is that the nature of the product will play an important part in shaping the industrial organisation around it. Whereas product structuring is one of the main topics of chapter 2, and section 2.8 will deal with industrial organisation around capital goods, this section will broadly consider innovation, or more broadly, technology management.

Miller *et al.* (1995) argue that innovation, in what they call complex systems, differs significantly from the conventional Schumpeterian model. In the latter the creation and diffusion of new technologies are seen as sequential activities, followed by a standardisation process aiming for a "dominant design" (Utterback and Abernathy, 1975). The life cycle goes from maturity to immaturity, involving radical product innovation in the beginning and more incremental (process) development towards the mature end of the cycle. However, in their case study in the flight simulator (FS) industry Miller *et al.* found evidence that:

> *In contrast with the arm's length market transactions of the conventional model, FS designs were negotiated ex ante by the main innovation agents, within an innovation structure designed to cope with uncertainty and risk. Unlike the mass market goods of the conventional model, FS products did not follow typical life cycle patterns but constantly evolved to meet the requirements of demanding users, regulators and professional bodies.* (Miller *et al.*, 1995: 397).

Miller *et al.* (1995) could neither identify dominant designs as understood conventionally (although commonly agreed standards emerged over time in the particular industry), nor did they support the general idea of industry shake outs during "technological discontinuities" (Tushman and Anderson, 1986). They furthermore expect similar patterns of innovation to be found elsewhere in complex system industries. According to them, this is mainly due to three salient facts: the evolving nature of the products, the institutional industrial structures and the active participation of users in the innovation process. In other words, innovation in complex products and systems can be perceived as user-producer driven and highly flexible as opposed to the formalised and supplier-driven innovation process in commodity manufacturing organisations (Hobday, 1998).

It shall be pinpointed that technological novelty might be present at both the lower levels of the product hierarchy, but also at the overall system level. This implies firms developing complex systems being dependent on technological capabilities in both breadth and depth (Prencipe, 2000). In an attempt to bring conceptual insight to the notion of complexity, Wang and von Tunzelmann (2000: 806) define "depth" as "the analytical sophistication of a subject", and "breadth" as "the range of areas that has to be investigated in order to develop a particular subject". In the case of products, they see depth as the "cognitive complexity embodied in the components", and breadth as arising from "the number of components and sub-assemblies involved, and thus the problems of interlinking them" (Wang and von Tunzelmann, 2000: 810). Of special interest to this thesis is the breadth-dimension. Bonaccorsi *et al.* (1996) claim that this dimension gives rise to a distinct kind of technological uncertainty they label "systemic uncertainty", which arises from the typical situation that:

> *…the behaviour of the system cannot be predicted on the basis of knowledge available at the level of individual components* (Bonaccorsi *et al.*, 1996: 544).

The creation of high volume goods is often perceived as a sequential path, where product development clearly precedes production. In the creation of large-scale, engineering intensive capital goods (such as CoPS), development and production/

construction are, in contrast, typically collapsed; we say that they are designed or engineered (and made) to order. Such projects then share characteristics with both two ‘ideal types’ of projects that literature addresses, namely: product development and delivery projects[1].

In project business, product development (in some cases even technology development) takes place during delivery projects, since that is basically the only opportunity to test the particular configuration in real world settings and to eventually see in what way a new design (or technology) in some component influences the rest of the system. This of course entails huge risks, which is one of the challenges in project business. Research on product development projects can be briefly be divided into two streams of literature: one that is concerned with innovation, technology strategy and research policy issues, and another more operations management-inspired. As Zhang (2004) notes few specific studies have addressed the mechanisms that link these. In the case of CoPS he therefore makes the distinction between make-to-concept and make-to-print in product development, corresponding to the concepts of make-to-order and make-to-stock in manufacturing.

On the other hand, the uniqueness and one-off nature of projects can actually be questioned, as was mentioned above. Clearly, capital projects consist of standardized components, module variants as well as engineered parts. When it comes to the whole, at least the constellation of all the parts (product configuration, service processes applied, location etc) of the project is unique and thus engineered.

Long product (life) cycles are typical for capital goods. This is not due to product complexity *per se*, but becomes important when looking at the further business opportunities attached to capital goods deliveries and will therefore be looked at in section 2.10.

2.7 Production characteristics: The operative environment of projects

Hobday (1998) asserts that CoPS typically are produced in projects or small batches. Indeed, the idea to categorise industries according to production process is not new (see Woodward, 1958; Hayes and Wheelwright, 1979). As said, the traditional operations management-based approach to project management has resulted in lots of useful tools and techniques. Among the best know are probably the work breakdown structure (WBS), the GANTT-chart and various network techniques such as PERT (project evaluation and review technique). The WBS is of particular interest for this study. In the PMBOK® Guide a WBS is defined as:

---

[1] Organisational change projects are often considered a third category of projects (see e.g. Söderlund, 2005).

> *A deliverable-oriented grouping of project elements that organizes and defines the total work scope of the project. Each descending level presents an increasingly detailed definition of the project work* (PMI Standards Committee, 2000: 209).

In a WBS the scope of a project is divided (decomposed or disassembled) into hierarchical packages of work. The idea is to provide project management with an "appropriate and effective level of project data" in order enhance a "clear vision of the end product and…the process by which it will be created". (Project Management Institute, 2001: 4).

There are several ways of perceiving a project in terms of WBSs. In the above definitions the word "work" is understood as an activity with a tangible result. Whereas such a perception serves its purpose in many cases, the problem with it is that it strictly speaking then also departs from a perception and not from the desired tangible output. Turner (2000) asks us what we actually manage, or ought to manage, in projects: "work, deliverables or resources" and suggests a return to the original use and meaning of a WBS, which takes it point of departure in the product breakdown structure (PBS). Another issue is to divide and assign the responsibility for the work (or product) packages defined. One approach here is to combine or integrate the WBS with an organisation breakdown structure (OBS) as Gray and Larson (2000) recommend. In the case of "complex system projects" Hameri and Nitter (2002) furthermore suggest the use of multiple breakdown structures (in their case project, assembly, as built and hardware breakdown structures). They stress the importance of linking the information between these structures and show how this can be done with the help of an engineering data management system.

The WBS concept and the underlying idea, especially when it comes to taking the PBS as an outset, come close to the concept of modularity (or more precisely, the concept of product architecture) as presented in the previous chapter. Both obviously constitute a central part of the theoretical frame of reference for this thesis and will be further discussed in section 3.2.

Apart from employing a distinct set of managerial tools and techniques, what does it really mean when something is produced in projects? In industrial terms the word "project" often has a connotation of either (or both) product development and design, or (and) construction and installation work. Whereas I dealt with the former in the previous section, this section focuses on the latter and on the project/production environment in general.

Lundin and Söderholm (1995) draw on the literature on organizational theory and introduce the important notion of "temporary organization" to clarify the contrast between permanent organizations and projects. They build their framework on the four basic concepts of time, task, team and transition. Furthermore, building on the work of e.g. Thompson (1967), they argue for an action- rather than decision-based view on projects. Action is needed to accomplish a specific task in a limited time with an internally committed and externally legitimised team in order to achieve transition, i.e. a change in the current settings - often the aim with projects.

Wikström and Gustafsson (1999) illustrate another quite fundamental difference between mass-production (or rather, process/flow production) and projects by comparing the value creation in paper production with that in ship-building. In the former the key to success is optimised and standardised operation, to a large degree sheltered from the surrounding world. Thus it is also sheltered from situations that mostly cause disturbances in production. Traditional operations management theory also tends to regard projects as closed systems. This is however in many cases a dangerous assumption due to the open nature of the project environment and thereby the impact of continuously occurring, unexpected situations.

The influence of the project environment has been emphasised in several other works as well. Youker (1992), for instance, maintains that many problems in projects originate from the project environment out of reach and influence for the project manager. Kreiner (1995), in turn, shows how vulnerable the originally relevant objectives of a project are in drifting project environments. This is partly why changes to plans have become more of a rule to than an exception in projects (Dvir and Lechler, 2004). Cova, Mazet and Salle (1996) further demonstrate the importance of managing the network relationships in the project environment, that is, what they term the "milieu", which will be further discussed in the next section (2.8).

Popper's (1996) work on propensities can be used as a basis for questioning the traditional, planning-focused view of projects. He argued that in our changing world, situations change all the time, with them the opportunities and thus also the propensities for certain outcomes. Projects are situation-rich contexts, both internally and externally, which must be seen as open and dynamic systems (Wikström, 2000). Situations have a large impact on how projects are managed, for instance: improvisation should be seen as a legitimate way of managing projects (Lindahl, 2003) and changes should be accepted (Dvir and Lechler, 2004); basically, the situations should be seen as the basis for all value creation in projects (Wikström, 2004). Obviously for similar reasons, Lundin and Söderholm (1995) argue for the action-based view on projects described above. Due to these reasons, Hellström and Wikström (2005) argue that well-structured products and state-of-the-art project processes and tools are not enough for the management of big delivery projects, but they have to be coupled with a set of "reflective actions". This argument partly draws on Donald Schön's (1983) notion of reflective and learning practitioners. In fact, one could argue that it is this through the reflection and intuitive decision making of their personnel that project companies receive full ability to act, learn and adapt as needed in the value creation process (Gustafsson and Wikström, 2004). The reflective element is maybe most obvious in handling the customer relationship, a process that hardly can build on solely rationalist, opportunistic behaviour (Gustafsson, 2002). For instance, even the aim of the project might not always be very well articulated by the customer. Instead the supplier needs to engage in a kind of sense-making process together with all or some of the other parties in order to increase the common understanding of what can ultimately be achieved (Alderman *et al.*, 2005). The element of sense-making might also be needed when the unexpected happens; in sorting out the reason and possible corrective action for the deviation at hand (Hällgren, 2004). In an ethnographic study of three power plant projects, Lindahl (2003) describes how such deviations are often successfully handled in, what at least looks like, a completely improvising and intuitive manner without the need for rigorous planning and control tools.

In conclusion, as we can see the business environment has both strategic, as in most industries, but also operational, unlike in many other industries, implications for running project-based companies.

2.8 Industrial coordination and the project milieu

> *Perhaps, the most salient image of CoPS is that of many organisations working together to realise markets, carry out production and agree innovation decisions ex-ante and during production, rather than in the conventional arms-length market-setting.*
>
> (Hobday, 1998: 707)

2.8.1 The interaction approach and relational view to industrial networks

Indeed, the networked way of delivery is a pertinent characteristic to the development and delivery of capital goods. Rarely can any one firm account for all the competencies and all capacity needed. And even if it could, the whole thing is probably best managed by dividing it into smaller units. This is why systems integration has emerged both as a central activity and more lately as a whole governance mechanism in project business (see section 2.10.1), connecting networks of actors participating in the delivery of projects (Hobday *et al.* 2003). Typically, several parties are involved: the project owner (the client), his consultant, regulators, a main contractor, sub-contractors, sub-suppliers, transportation firms etc, each contributing with aims and wishes as well as knowledge and competencies essential for successful completion of the project. Although networks have become a buzz word in all business, advanced by especially the IMP-group[1] (Industrial Marketing and Purchasing), it is merely where the implementation of many big capital projects has started from. However, before taking a closer look at the peculiarities of project-based networks, let us first consider the changes going on in industrial markets in general, as it is of great importance to the former as well.

During the past decade or so there has been a great change in how we look at supplier relationships. Previously, company networks were like those large mechanistic firms organised according to supply chain structures and focusing on economies of scale that Hobday (1998) describes. The issue was then mostly studied under the label of vertical integration, posing the question whether it is better for the firm to make a component internally governed by "the visible hand" of managerial hierarchy, or to rely on an external market for the exchange of goods and services (see e.g. Chandler, 1977; Monteverde and Teece, 1982; Walker and Weber, 1984). In the beginning of the 1990s companies had increasingly started to focus on their "core competence" (Prahalad and Hamel, 1990) and thereby to rely on "the invisible hand" of the market for non-core parts of their business. Consequently, the issue of how to best handle supplier relationships has evolved on the top of the management agenda (Gadde and Snehota, 2000). In an extensive study on the differences between US and Japanese automakers Dyer (1996; 1997) find that transaction costs do not necessarily increase with higher supplier specialisation. This he attributes to especially the trustworthy collaboration between Japanese suppliers and buyers. Indeed, the central theme for the IMP-group has been an interaction rather than transaction approach to supplier relationships (Håkansson, 1982; Johanson and Mattsson, 1987). Emphasising the importance of the interactive relationship, the IMP-group originally challenged traditional ways of looking at industrial marketing and purchasing on four points (Håkansson, 1982):

- The focus on discrete purchasing events.
- The suggested manipulative behaviour of buyers towards passive sellers.
- The assumed atomistic nature of industrial markets.
- The separation of the industrial purchasing and marketing activities.

Gadde and Snehota (2000) however remind us that simply relying on the notion of "making the most of supplier relationships" might be dangerous, because as both

---

[1] http://www.impgroup.org/

they and Dyer (1997) note, developing relationships costs. Dyer (1996) lists three factors that might influence the efficacy of transaction specific investments:

- institution/contracting environment
- industry uncertainty
- product/task interdependence (complexity).

Whereas technological uncertainty has partly been touched upon in section 2.6, the contracting environment is a delicate issue and deserves some comments. As Sako (1991) has suggested trust seems to be a key to more favourable contracting environments and consequently to lower transaction costs. However, as Gustafsson (2002) points out the concept of "trust" is philosophically obviously a difficult subject to deal with. Namely, most researchers tend to take the perspective of an objective observer, whereas the act of trusting only can be fully understood by adopting the view of the one who trusts (or not), he argues (see also Lagerspetz, 1998).

The influence of the product/task interdependence, and thereby interfaces, on the issue of vertical integration has already long been acknowledged in management literature (Walker and Weber, 1984; Dyer, 1996). Since product/task interfaces already were addressed extensively in the first part of this chapter, I shall here only focus on the related topic of resource interfaces. Araujo *et al.* (1999) propose a taxonomy of four kinds of interfaces through which a customer can access its suppliers' resources:

- Standardised – no directions, no interaction.
- Specified – precise specifications.
- Translation – direction given by desired functionality.
- Interactive – joint development.

On the basis of this categorisation Araujo *et al.* (1999) make three suggestions. First, companies are likely to need all four types of supplier interfaces in order to balance innovation and productivity. Second, as implied above, there is a need to understand the interdependence amongst interfaces in order to develop an integrated view of the company's resource base. Third, due to the need for variety in interfaces, there is a danger in focusing too narrowly on core competencies.

2.8.2 Project-based business networks

One of the main differences between other industrial networks and the project-based organisation is the temporal nature of the latter (Lundin and Söderholm, 1995). This again has several implications for the management of project business networks. For instance, Hadjikhani (1996) demonstrates the significance of an active "sleeping relationship" during periods of discontinuity in order to anticipate further orders, thus pinpointing the 'before' and 'after' dimensions of project selling. Cova *et al.* (1994; 1996) share the same concern and go beyond 'the competitive bidding of project marketing', i.e. being merely reactive, by introducing the practitioner-originated concept of "milieu" to the academic audience. Cova *et al.* (1996) demonstrate how the evolution of practise in project marketing has gone from a focus on unique and isolated projects, to the management of portfolios of projects, and further on to linking up with central actors (other than potential customers) and finally a smooth transition to the recognition of the territorial network around connected projects, i.e. being more proactive. Consequently they also call for a shift in (research) focus from the single project to the wider milieu. They describe the concept as "a socio-spatial configuration that can be characterized by four elements" (Cova *et al.*, 1996: 654) :

- a territory
- a network of heterogeneous actors related to each other on this territory
- a representation constructed and shared by these actors
- a set of rules and norms ("the law of the milieu") regulating the interactions between these actors.

Cova and Hoskins (1997) argue that firms may approach the milieu from two fundamentally different standpoints: a deterministic approach, anticipating "the law of the milieu", or a constructivist approach, actively participating in the shaping of those rules.

The milieu may come into existence, and gains significance, when project business becomes repetitive, and projects are geographically bound and belong to a certain sector (Cova *et al.*, 1996). A typical sector in this regard would be the construction industry, which also served as the empirical case in Cova *et al.'s* study. However, despite the potential and the fact that construction is in the front in terms of outsourcing, Dubois and Gadde (2002a) show that reliance on partnering and strategic networking is still rare and that focus on transactional exchange largely prevails in construction. They found this to be the case both at the level of the permanent and at the level of the temporary network[1].

Owing to both discontinuity in the market and heterogeneity of the product the learning process constitutes another major issue for project companies, both internally, in terms of maintaining technological capability, and externally, in terms of maintaining control of technological development among sub-suppliers (Bonaccorsi *et al.*, 1996). Due to these reasons Prencipe (1997) argues that companies supplying, what he labels, product-systems cannot rely on simple and static notions such as core competencies if they want to manage the evolutionary dynamics of their systemic product. Instead, he argues, system companies need capabilities at both the architecture and the component level of their product (Prencipe, 2000).

Hobday (1998; 2000) pinpoints the creative dimension of projects. In that light his description of large projects as organic and elaborate networks of actors can be well understood. In a comparison of the pros and cons of the project-based organization (PBO) with the more functional matrix organization he (2000) concludes that the PBO is an ideal form for managing CoPS, or, in general, for managing large scale, innovative and risky projects that has to be coordinated among different firms. However, the PBO shows inherent weakness in achieving what could be broadly referred to as economies of scale. In slight contrast to Hobday's arguments, Keegan and Turner (2002) conclude from a study in 22 firms that although many project-based firms have mechanisms in place to foster innovation, the often "strict control and evaluation methods appears to stifle innovation". As there apparently is a difference between what Hobday (2000) term PBO and Keegan and Turner's definition of project-based firm, this points at another important conclusion that stems from Hobday's work, namely that there is:

> *… a variety of choices involved and the need to match organisational form with the product mix in question* (Hobday, 2000: 893).

2.9 Characteristics, future and importance of project business markets

Bonaccorsi *et al.* (1996) suggest that system products be classified along two different dimensions: nature of technology and nature of demand. As product characteristics were the topic of section 2.6 this section will focus on the latter.

---

[1] Dubois and Gadde's (2002) study was carried out within the Swedish construction industry, why the results strictly speaking indeed cannot be generalized internationally. However, to my knowledge the described issue is often considered a syndrome of particularly the construction industry. The purpose here is anyway merely to show that not even in contexts where it would seem likely 'real' partnering has not been achieved.

In order to contrast the characteristics of project marketing with those of industrial marketing in general researchers of project marketing, in their turn, often make reference to the DUC-framework (Discontinuity, Uniqueness and Complexity), originally developed by Mandják and Veres (1998; Skaates and Tikkanen, 2003; Cova and Salle, 2005). Whereas discontinuity and uniqueness has been discussed above and thereby should be clear, complexity is here understood as the complexity in project relationships. In addition to product complexity and the earlier discussed milieu-phenomenon, this may partly be a reflection from what Bonaccorsi *et al.* (1996) have identified as buyers' complicated decision making process and varying specification capability, as well as from what Hobday (1998) describes as "bureaucratically administered and politicised markets". An indication of this complexity is also the more extensive marketing cycle for projects compared to other industrial goods (see Table 2-e). Indeed, as Davies (1996) shows, the development of large technical systems can be fully understood only through a framework that accounts for both social and political will and the economic drive for scale, scope and system advantages.

However, there are changes going on that are likely to induce changes to the elements of the DUC-framework. In their 1996 editorial in the *International Business Review* Günter and Bonaccorsi list five general changes in sight that they expect are going to change the competitive conditions in project- and system-based markets:

- Economic growth in East Asia.
- Liberalization, privatisation and internationalisation of procurement in public utilities.
- Centralization of procurement in multinational corporations.
- Shortening of procurement cycle.
- Financial shortage.

In another editorial in *Research Policy* Hobday, Rush and Tidd (2000) recognize the same kind of future developments and call for research in the corporate strategy area of CoPS. Both editorials see increased service provision as a future trend in the kind of project business they deal with. One such service, crucial to many project companies, is systems integration (Davies, 2004). Hobday *et al.* (2003a) call for more research in this arena, notably concerning the strategic implications of it across industries.

Table 2-e **Comparing seller and buyer perspectives of the project marketing cycle (Cova and Holstius, 1993: 111)**

Seller's side	Buyer's side
A – Search	Need awareness
	Research on suppliers and contact for
B – Preparation	Specifications
	Bidder's list
	Request for proposals
C – Bidding	Exchange of information
	Analysis of proposals
	Short-list
D – Negotiation	Negotiation
	New proposals
	Analysis of proposals
	Negotiation
	Final assessment
	Final selection
	Contract
E – Implementation	
F – Translation	

There seems to be an industrial bias towards project business sectors in the Finnish economy, with annual sales up to US$ 30-40 milliards and an employment of some 150,000 people (Artto *et al.*, 1998). According to some estimates this accounts for some 30% of the Finnish exports, whereas in, for example, England almost half of the GDP is built up from project-oriented activities (Wikström, 2000). Acha *et al.* (2004) report from a study on the contribution of CoPS-based industries to the UK economy. According to their classification scheme CoPS account for some 19% of the overall production and gross value added, amounting to some 1.2 million employment.

2.10 Competitive strategies: Systems integration and other business concepts

"Business model/concept" is an often used concept used to denote the fundamental strategy underlying a company's activities, heavily popularised during the so called 'dot-com era'. It can be classified as belonging to the group of "logic concepts" in strategy literature, which have their origin in Normann's (1975; 1977) conceptualisation of "business idea", and to which among others Porter's (1985) influential "value chain" and "activity systems" (Porter, 1996) concepts belong (Brännback and Näsi, 2004). For the purposes of this thesis I will use Horsti's and Brännback's wider definition of what a business model is and should contain:

> *Any business model will be an operationalization of the purpose and the objectives of the business, i.e. the business strategy. A business model describes basic structure of offering, transaction flows and roles of the participating parties in a company's every-day business* (Horsti and Brännback, 2004: 4).

2.10.1 Systems integration, project capabilities and project-based business networks

Systems integration capabilities are often envisaged as the distinguishing and essential ability of companies supplying systemic capital goods (Bonaccorsi *et al.*, 1996; Hobday, 1998; Prencipe, 2000). "Systems integration", seen as part of "systems engineering", is a widely used concept in engineering and used to refer to merely technical activities within the firm. The *International Council on Systems Engineering* gives the following definition:

> *Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem…* (INCOSE, 2005).

More lately systems integration has become a strategic concern to many companies and industries and could today be said to have evolved as much as an organisational form and governance mechanism (Hobday *et al.* 2003). Still, in the general management literature the topic has until recently acquired little interest. Such recent contributions include for example McCord and Eppinger (1993), Bonaccorsi *et al.* (1996), Prencipe (1997; 2000), Brusoni *et al.* (2001), Prencipe, Davies and Hobday (2003) and Davies (2004). According to Bonaccorsi *et al.* (1996) systems integration requires special skills different from those found in traditional manufacturing, including:

- dealing with systemic uncertainty (see section 2.6)
- operating under incomplete planning (see both section 2.6 and 2.7)
- backward thinking (design hierarchy attribute)
- managing conflicts (especially in terms of efficient supply and unique demand).

Whereas systems integrators clearly are in need of a whole range of technological capabilities, in both breadth and depth (Prencipe, 2000), Davies and Brady (2000) suggest "project capabilities" be an additional skill set of CoPS-companies when it comes to 'organisational' capabilities. Introducing the concept of "project capabilities" they extend Chandler's (1990) organisational capabilities framework, which covers strategic and functional capabilities. Partly drawing on March (1991) they present a three stage project capability building-model covering the learning from early vanguard projects when companies move into a new technology/market, later project-to-project and final project-to-organisation learning. The model shows how companies successively may move from bottom-up explorative learning to top-down exploitative learning, in order to reap what Davies and Brady (2000) earlier termed "economies of repetition" from delivering "repeatable solutions".

Earlier we saw that business networks are of utmost importance for project and system companies (Cova *et al.*, 1996; Hobday, 1998). Consequently "orchestration" has become the appropriate management characteristic of modern projects (Laufer, Denker and Shenhar, 1996). Even for established project businesses with considerable in-house capability, it seems wise to rely on more unstable organisational structures in the form of a network of suppliers in order to cope with discontinuity and fluctuation (Hellström and Wikström, 2005b). Brusoni *et al.* (2001) expect such loosely coupled networks to become even more important in the future. They however assert that in order to both tighten the links within its network and to manage the technology dynamics of their products, project companies need to retain a broad set of in-house capabilities; i.e. "to know more than they need for what they make" (Brusoni *et al.*, 2001: 620). In addition to more technological means of controlling a business network, Skaates and Tikkanen (2003), using a marketing perspective, distinguish between three postures of project companies for controlling their competitive environment: a deterministic, a constructivist (Cova and Hoskins, 1997) (see section 2.8.2) and an extreme control posture, in which project companies are urged to control both the technological and demand dynamics in its industry environment (Bonaccorsi *et al.*, 1996).

2.10.2 Increased customer orientation: towards integrated solutions

In almost any business increased customer orientation seems to be one of the strongest management paradigms of today. Therefore, traditional project requirements of conformance to schedule, budget and quality are replaced by an ambition for performance in all regards (Maylor, 2001). In that sense Gaddis' (1959/1991) statement of the project manager's job, could be extended to not only creating the product, but value. This touches upon another, related phenomena. Namely, many scholars have actually started to emphasize the utility aspects of products and urge for a movement from manufacturing towards services and service management (see e.g. Normann, 1983; Quinn, Doorley and Paquette, 1990; Grönroos, 1994; Johnston, 1994). This has led to an increased scope of also services offered by the supply side. Beginning with Mattsson (1973; for a review see 1996) researchers in industrial marketing have studied this phenomenon under the label of "systems selling", which deals with the supply of integrated goods and services. In this vein, Kosonen (1991) defines a system as a sales object as consisting of physical goods, know how and system specific services.

Clearly, capital goods and thereby also project business is a blur of goods and services. Starting from its per definition unique nature, every single capital good project involves, at least to some part, development activities (design and engineering, i.e. services). The activities in the value chain of the production phase of projects are however performed in a different order compared to those of typical mass-production industries. In short, i.e. the flow of materials (distribution) in mass-production is often perceived as divergent, whereas projects rather are perceived as convergent. This is largely due to the systems integration (hierarchical) aspect of projects, that is, that big capital goods can often be divided into several sub-systems, which themselves can be big projects. For some years, the concept of systems integration has also been widely used in especially the automotive industry. However, in project business, notably in the defence industry, it has been a basic feature since the early days of project management in the 1950s. Also as a result of the above points, projects contain one type of services not readily found in traditional manufacturing, namely that of project management itself. Already Normann (1983) listed "management and organisation" as one type of service products. However, when we buy our shoes or other commodities, we usually do not think of it as buying the service of operations management from the shoe manufacturer. In contrast, a customer planning a capital investment is likely to ponder upon whether to let somebody else take care of the management of the up-coming project or how to split the project between concerned parties. In some cases the management of a project is not easily de-coupled from the system delivery, but indeed there are firms that explicitly sell project management services, e.g. the Finnish engineering and consulting company Jaakko Pöyry[1].

Another characteristic of the capital goods industry is the fact that both pre-sales and after sales activities are more extensive, regardless of which party takes care of the activity in question. For instance, extensive pre-feasibility and feasibility studies are usually carried out. These could be regarded as an integrated form of technical and business consulting, i.e. also a form of services. Likewise, the operational (including maintenance) requirements of large capital goods are extensive and, indeed, have traditionally constituted the business of the customer. However, during the past few years we have seen some of the world's leading suppliers move into operations, too. How far downstream the supplier can move varies between industries and the move indeed does not come without problems and failures (Davies, 2004).

The business of delivering capital goods is clearly a global business. Major heavy machinery suppliers operate all over the world. With tons of goods moving through several country borders logistics becomes a demanding task itself, especially as import and heavy transportation regulations tend to vary a between countries and states. Moreover, the supplier often needs to adapt its operations to the local geographical, physical and social circumstances. All this often implies the application of extra services, some being what Grönroos (2000) calls not-invoiceable. This is not merely a question of service standardization, but rather a question of limited functionality of artefacts. If the equipment does not fulfil the functional requirements asserted upon it during its life-cycle that particular product is likely to reduce the profitability of the whole project. And if we yet take into account the operation phase of the life-cycle, the functionality aspect becomes even more obvious. Consequently issues like life-cycle engineering, design for manufacturing and design for serviceability (Ishii, 1998) are most important for this line of business. In effect, it is not that different from the service management perspective, perhaps merely engineers' way of perceiving the idea of value chains.

Today system sales is slightly changing nature towards an ever more customer driven activity and hence popularly labelled "solution providing" (Foote *et al.*, 2001). For the special case of engineering-intensive systems and accompanying services, the term "integrated solutions" is used (Wise and Baumgartner, 1999; Davies *et al.*, 2001; Davies *et al.*, 2003; Davies, 2004). In project business this has been seen as a demand and supply development in favour of turnkey and EPC-deliveries (see e.g. Wikström, 2000). In addition to the system product, it now even seems that the demand side in the capital goods industry is ready to go even further by outsourcing both operation and maintenance, and by requiring both financing and consulting services from the

---

[1] http://www.poyry.com/fi/index.html

supply side according to Figure 1-2 (Davies *et al.*, 2001). In fact, not only former manufacturers move into service business, but also service providers enlarge their offerings by increasing their upstream capabilities (notably systems integration). The common denominator for such firms seems to be an attempt to take over a part of the activities that their customers used to perform themselves, so in order to provide whole solutions. (Davies, 2004).

To succeed in such above described service-led projects becomes a matter of hitting a moving target (Alderman *et al.*, 2003). In fact, the customer's view of a supplier is largely built up in the interplay between the overall pre-picture the former has of the latter, and the immediate actions of that one. Customer satisfaction shall thus be regarded as the continuous process of maintaining the relationship throughout the project, during the warranty period and even thereafter in order to support the customer in operating the utility delivered. (Gustafsson, 2002) Consequently, a definitive business model for integrated solution providers becomes difficult to prescribe due to the dynamism in this type of business (Brady *et al.*, 2005). However, Davies *et al.* (2003) description of an organisational model for integrated solution providers, constitute a promising attempt to face this issue. In part drawing on their earlier work (Davies *et al.*, 2001), they extend Foote *et al.*'s (2001) solution provider model (see section 1.1) as shown in Figure 2-4. One major difference is that Davies *et al.* (2003) account for the fact that the deliverers of large-scale, engineering-intensive products typically have to rely on an extensive network of suppliers.

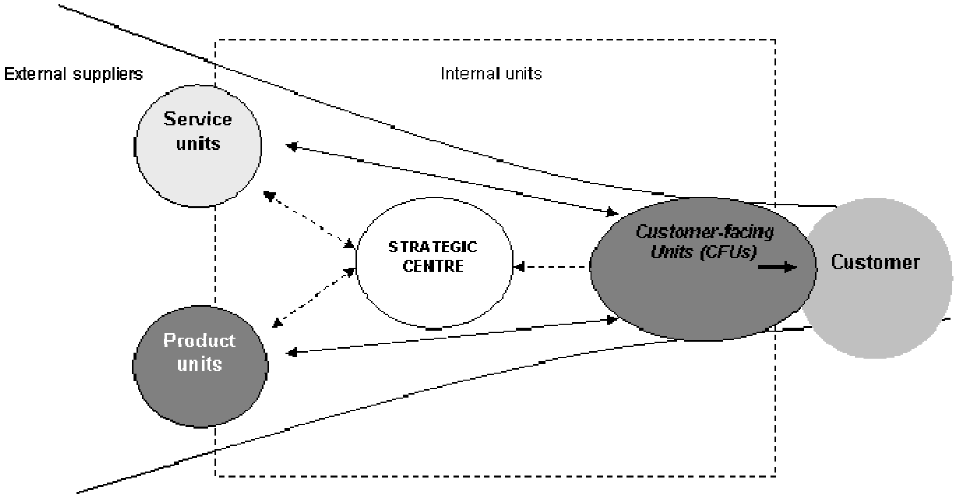


Figure 2-4 An organisational model for delivering integrated solutions (Davies *et al.*, 2003: 17; Davies and Hobday, 2005: 242)

Laufer *et al.'s* (1996) description of the change in project management styles since the 1960s (see Table 2-f) fits the above arguments above. According to them the evolution has gone from a predictable environment, where it is possible to mainly focus on planning and controlling the projects, towards a more unpredictable, fast environment where the requirements on the project managers have broaden and partly changed.

Table 2-f Evolution of project management (Laufer et al., 1996: 190)

Central concept	Era of model	Dominant project characteristics	Main thrust	Metaphor	Means
Scheduling (control)	1960s	Simple, certain	Coordinating	Scheduling regional flights in an airline	Information technology, planning specialists
Teamwork (integration)	1970s	Complex uncertain	Cooperation between participants	Conducting a symphony orchestra	Process facilitation, definition of roles
Reducing uncertainty (flexibility)	1980s	Complex uncertain	Making stable decisions	Exploring an unknown country	Search for information, selective redundancy
Simultaneity (dynamism)	1990s	Complex, uncertain, quick	Orchestrating contending demands	Directing a three-ring circus continuously switching acts based on the crowd's response	Experience, responsiveness and adaptability

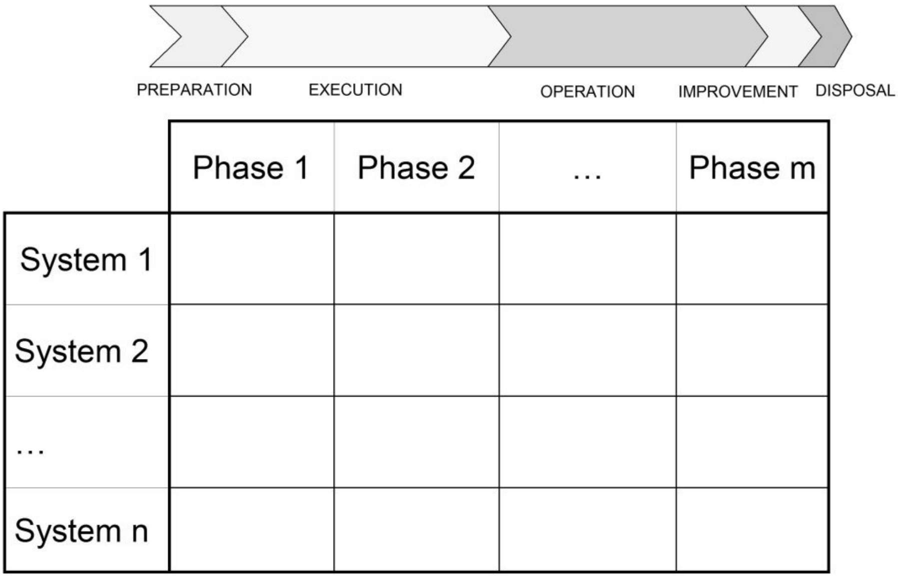
Foote *et al.* (2001) claim that becoming a solution provider requires fundamental rethinking within the organisation. They suggest a clear distinction between capability-based back-end units and customer-based front end units. According to their vision the role of the back-end units would among other things be to standardise and modularise products and services to be solutions ready, whereas the front end units would serve as so called "configurators" (for an explanation of the concept see the section on mass customisation and configuration in section 2.2.3). Issues regarding modularisation of physical products are dealt with quite extensively in management literature, both regarding commodities (e.g. Langlois and Robertson, 1992; Ulrich and Eppinger, 1995; Baldwin and Clark, 2000) and, although to smaller extent, capital goods (e.g. Nilsson *et al.*, 1999; Wikström and Storholm, 1999; Brusoni and Prencipe, 2001; Hoare and Seiler, 2001). The intangible side however still lacks a rigid foundation, although there is a common danger for many solution providers to be caught in what Meier and Piller (2001: 4) calls the “service trap”, thereby creating unnecessary cost and ‘non-invoiceable services’ (Anderson and Narus, 1995; Grönroos, 2000).

Summary of the theoretical implications

This section serves to extract some of the more important implications that arise from the literature review into a loose but consistent theoretical framework.

According to Pettigrew (1997), the problem with case studies is that they are often presented as atheoretical, descriptive case histories. He maintains that one of the most typical deficiencies is the failure to relate the case to existing theory and research. In this chapter I have reviewed two bodies of literature I consider relevant for my research: that of modularity and project business. To facilitate a more structured empirical process I shall here start with constructing a more rigid framework by combining the two bodies of literature at hand. There is of course a risk in doing so, in that the research process becomes too deductive and merely serves to support (or not) existing theories, which is not the purpose of this thesis. Pettigrew (1997), however, rather considers such deductive structuring to enable a more open-ended inductive process. The inductiveness in this thesis is secured through the use of the results in practical cases. Furthermore, it is to be pointed out that the practical problems have as much, if not even more, served as decision parameters for the choice of relevant literature as the latter has determined the outcome of the analysis and interpretation process. This way clinical (or processual as Pettigrew calls it) research can be described as "interactive cycles of deduction and induction" (Pettigrew, 1997).

Two dimensions stand out from the literature review in this chapter, namely, the 'vertical' hierarchy of a modular system and the 'horizontal' delivery chain (or value stream) of project business. Basically, in delivery projects the systems (or the products) 'travels' over the chain in order to reach the project objective of an operating facility. The idea is depicted in Figure 2-5.



	Phase 1	Phase 2	…	Phase m
System 1				
System 2				
…				
System n				

Figure 2-5 The framework: the product-process palette in project business

Regarding the palette (or tray) reference can be made to the WBS-technique in project management (presented in section 2.7). The difference to traditional WBSs is that in the tray the project breakdown is presented in two dimensions. Furthermore, then project management can be considered a third dimension, which has to ensure the systems integration on the y-axis and the phase-to-phase coordination on the x-axis. This three-dimensional tray constitutes the basis for the theoretical frame of reference used in this thesis. Below I will still clarify and repeat some relevant details of modularity and project business.

With regard to Q1) we know from chapter 3 that modularisation is indeed not to be equated to standardisation, which is but one of the potential ways we can benefit from modularity. We rather ought to see modularity as a product or systems architecture attribute that can yield a long list of different advantages. Commonly, modularity is advocated as a way of managing complexity through the creation of independent modules. While this is true but rather abstract and most other benefits can be derived from this independence criterion, I proposed in section 2.1 a more 'practical' definition as the basis for this thesis:

> *Product modularity is a systems design strategy that can be used to 1) manage complexity by hierarchically decomposing a whole into parts and by mapping functions to parts in order to minimise interdependencies, to thereby enable the pursuit for 2) economies of scale by standardising such parts and 3) variability through standardised interfaces that allow the use of interchangeable such parts, or 4) other such benefits.*

We also learned that the choice of product or systems architecture in fact is a major decision variable for manufacturing companies (Ulrich, 1995). In the same chapter we saw how architectures can be analysed by using relational matrices (Pimmler and Eppinger, 1994) and how sub-systems can be categorized as modular or integrative systems (Sosa et al., 2003). We then learned that the process of creating an architecture, a module or a dominant design, is basically an emergent and social process (Anderson and Tushman, 1990) that follows the strategic direction a company chooses (Erixon, 1998). This means that a single, ultimately optimal architecture (or modular breakdown) hardly exists (or is very difficult and time-consuming to attain), but that several good alternatives are available. The characteristics of a 'good module' is obviously dependent on how well it addresses the different benefits of modularity and outweighs its disadvantages listed in section 2.2, and how well it works in the project setting along its extensive life cycle. Moreover, we saw that in the automotive industry there is a tendency to consider modularity from at least four viewpoints: modularity in design, modularity in production, modularity in use and modularity in interfirm relationships (Sako, 2003; Takeishi and Fujimoto, 2003).

Maybe even more importantly, in chapter 2 (notably section 2.4) we learned that by looking at the product structure we can, if not predict, at least make an educated guess about the need for technical communication and coordination between teams designing different sub-systems of the product. In fact, the relational matrices also allow us to analyse the information structure of a project. This line of reasoning consequently takes us closer to Q2). According to Parnas' (1972: 1056) principle of "information hiding" a project ought to be decomposed so as to minimise the visible design information, that is, the information that teams designing one module need other from those designing other modules. The rest of the information content in modules should thus be "hiding". In chapter 2 we also got an idea about how the choice of product structure and organisational architecture interacts (Henderson and Clark, 1990; von Hippel, 1990; Sanchez and Mahoney, 1996; Oosterman, 2001; Sosa *et al.*, 2004).

The works cited in this section have so far mainly considered the design phase of a project. If we then, in addition, consider the other phases of a delivery project our task again becomes more complex. This takes us back to section 2.3.5, where we saw that the phases differ very much and thus require very distinct capabilities and assert very different demands on the products/modules. However, the current trend among many world leading companies is the move towards providing “integrated solutions” (Davies, 2004), which I specifically discussed in section 2.10.2. For “solution providers”, business becomes a matter of managing both physical product architectures as well as more intangible features of the products, such as those entailed in the design, installation, operation and maintenance of the product. As I discussed in chapter 3, the partitioning of these tasks (von Hippel, 1990) and the management of the interfaces between them become key issues, too (Adler, 1995). These ideas lie at the heart of Q2) and constitute to that part the frame of reference for the research problem. However, it tells us little about the management of single, ‘modularised’ projects, which is the other part of Q2). To address this side of the problem I will make reference both to traditional, deterministic project management theories (PMI Standards Committee, 2000) as well as to more recent approaches that emphasise the emergent, intuitive and reflective elements of managerial action (Gustafsson, 2002; Lindahl, 2003).

3 RESEARCH DESIGN AND METHODS

> *…I reject the whole idea of design methods as a subject of study, since I think it is absurd to separate the study of designing from the practice of design. In fact, people who study design methods without also practicing design are almost always frustrated designers who have no sap in them, who have lost, or never had, the urge to shape things. Such a person will never be able to say anything sensible about "how" to shape things either.*
>
> (Alexander, 1971: preface)

Taking Alexander's advice this study on structure is not separated from the practice of structuring. As outlined in section 1.4.3 this thesis makes use of a clinical approach. Social clinical work typically does not follow predefined rules, but rather acts upon emerging situations. Consequently, the inductive part of this thesis resides in a bricolage of heterogeneous sets of data from different sources, collected by making use of a wide array of methods. This is however no excuse for lack of scientific rigor. The purpose of the first part of this chapter is thus to bring order and transparency to the research process behind this thesis. The chapter is structured as follows. First, I will describe the empirical process in terms of research design and data sources. Thereafter I present the main principles and methods used for the data collection and analysis process. I will finish the first part by discussing the connection between theory, data and objectives. The second part of the chapter then presents the cases studies in more detail.

3.1 The clinical research process

I have already discussed the methodological approach of this thesis in section 1.4. As for the philosophical foundations of this research, I articulated a pragmatic view of social science. This allows me to make use of a clinical research strategy, which I have applied to two cases: ship building and energy systems delivery (hereinafter referred to as the "ship case" and the "energy systems case"). The choice of these two particular industries can be justified making reference to access (Gummesson, 1985) and theoretical sampling (Eisenhardt, 1989), that is in this case, by the fact that the phenomenon under scrutiny is present in both, or even more importantly, the investigation of it is relevant for both. To what extent the two cases are representative for the two industries in general will not be discussed here. For the time being the cases are rather to be seen as 'local' business communities.

To continue the description of the research process in terms of Denzin and Lincoln's (1998) five phases, the research design of this thesis can now be perceived in the light of the action research cycle (Figure 1-3) applied on the two cases, as shown in Figure 3-1 (the roman numbers refers to the five phases of qualitative research).

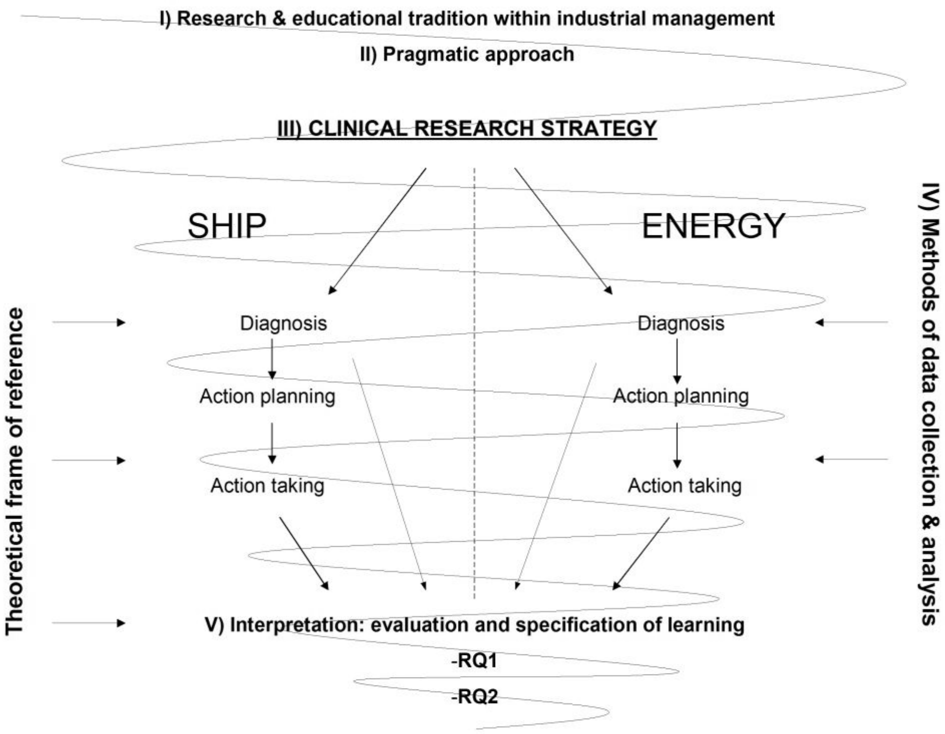


Figure 3-1 The research design of the thesis

However, the two cases are not internally entirely coherent, but are rather to be seen as two externally similar cases. Both cases are mainly built upon two major development programmes: the EU-directed "Intership" programme in the ship case and the Tekes[1]-initiated "DENSY" programme in the energy systems case.

Intership[2] is an applied research programme with the ultimate aim to increase the competitiveness of EU shipbuilders. The focus is on complex one-of-a-kind vessels. The programme also aims to improve vertical integration within the maritime communities and horizontal cooperation between the EU shipyards. More officially, the following main objectives are set (Intership 2005):

- Increasing significantly the competitiveness of […] cruise and ferry shipbuilders…
- Development of better products, considering the entire life cycle of complex ships…
- Drastical *(sic)* reduction of building and development cost as well as time-to-market of innovative solutions…

One of the six main themes in Intership is modularisation, which is the subproject that this thesis is builds on.

DENSY[3] is a national (Finnish) technology programme for distributed energy systems. The overall objective of the programme is to assist Finnish industry in developing products and services for the global market. One of the focal areas of the programme is the development of business concepts for companies on the distributed energy systems market. The sub-project that the energy systems case in this thesis builds on addresses the business concept area. For the project the following specific objectives were set:

- To create a product-service palette for the consortium.
- To develop a process for modularisation according to functionality.
- To outline the procedure for creating and maintaining a business network.
- To create a new project management process, for the planning and controlling of a modularised project.

---

[1] The National Technology Agency of Finland; for more information, see http://www.tekes.fi/eng/.

[2] http://www.intership-ip.com/partners.phtml

[3] http://akseli.tekes.fi/Resource.phx/enyr/densy/index.htx.

With regard to the above, one can conclude that a common denominator for both programmes (cases) has been the aim to render the respective industries more 'modular'. However, the objectives and content of the programmes has not fully coincided with that of this thesis. Therefore I complement with material from other research projects, some of them carried out in close connection to the two major programmes. In addition, my working experience from the energy systems industry can be considered the starting point for the whole research process. In sum, the empirical data sources for this study are (in a more or less chronological order):

Table 3-a The empirical data of the thesis

SHIP	ENERGY SYSTEMS
1. Pre-understanding[1] (Hellström, 2002)	
S-2. Intership[2] (Hellström and Wikström, 2004; 2005a)	E-2. DENSY[3] (Hellström, Gustafsson and Wikström, 2005)
S-3. Findings from a research programme in the Finnish marine cluster ("MERIKE")[4] (Wikström, Westerholm and Toivola, 2004)	E-3. A customer survey for [Company X] (Gustafsson, Wikström and Haikkola, 2003)
S-4-7. Four DSM-based studies for various ship system suppliers (Hellström and Westerholm, 2005; Wikström, Hellström and Westerholm, 2005)	E-4. A DSM-based study in [Company X] (Gustafsson, Hellström and Haikkola, 2005)

Next, I shall show how the different data sources link to the research process and later what impact they have had on the findings.

The work done in the main programmes (number S-2 and E-2 in the list above), complemented with results from projects S-3 and E-3, has served this thesis mainly in by providing current state surveys for both industries. It can hence be said to correspond to the diagnosis phase of action research. Based on the work done in these

---

[1] For general information on the project, see APPENDIX 1.

[2] For general information on the project, see APPENDIX 1.

[3] For general information on the project, see APPENDIX 1.

[4] For general information on the project, see APPENDIX 1.

programmes and projects (S-2-3 and E-2-3), some more specific projects have been initiated (S-4-7 and E-4), where the main purpose has been to study the product-process structures of certain product systems in respective industries in order to suggest a way further towards more modular structures. This has been done with the help of the DSM technique introduced in section 2.3.2. The DSM studies can be considered a part of the action planning process, although it contains elements of both diagnosis, through the analyses, and action taking, through the re-structuring (or rather re-perception) of the systems. Some of the results of this planning process have then been taken further to implementation in the programmes S-2 (and S-3) and E-2 above.

The research process behind this thesis has not always proceeded in a straight forward manner according to clear phases as Figure 1-3 and Figure 3-1 would suggest. Still, both diagnosing, planning and action taking activities can be identified among the research activities that constitute the empirical base for this thesis. Neither have these activities always followed each other in a perfectly sequential order; at times they have, at other they have been carried out concurrently or in an iterative manner. One could also say that the overall research process has proceeded in smaller action research cycles[1]. Thus Figure 3-1 mainly serves the purpose of providing an overview of the research design, rather than exactly outlining how the pieces of this research links to the action research cycle. After all, this has been a clinical rather than a strict action research process. Furthermore, a distinct feature of the research process is the way the two cases have interacted. A more detailed and authentic picture of the research processes behind this thesis, embracing among others the above mentioned issues, is provided in Figure 3-2.

---

[1] In fact, also this whole thesis can be seen as a whole diagnosis and action plan preparing for further industrial action.

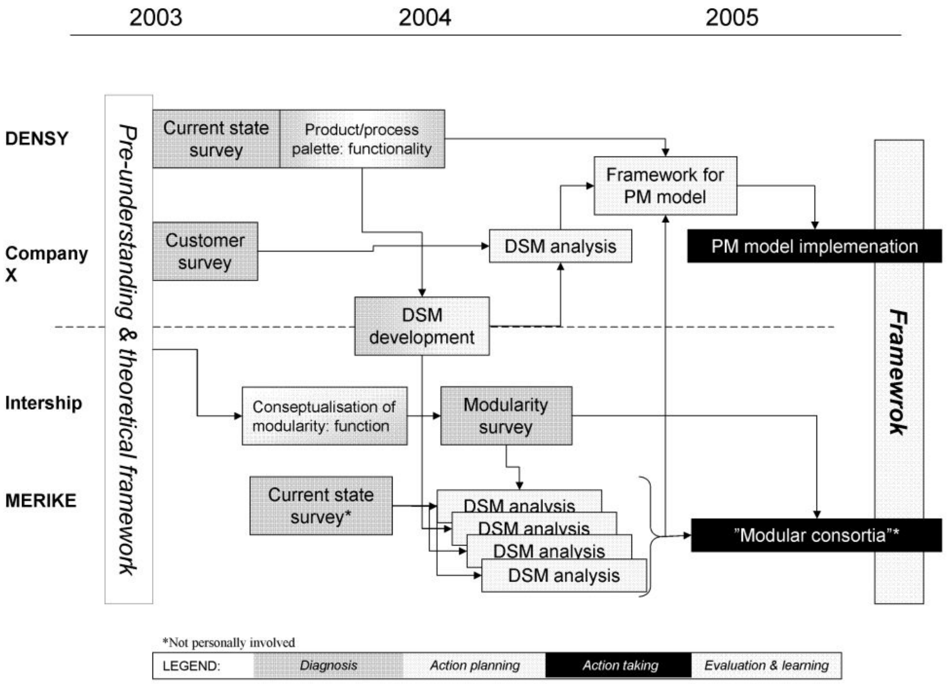


Figure 3-2 The research process behind the thesis shown as a flow diagram

The description of the research design will now proceed as follows. In the next section I will briefly describe how the research has been carried out in terms of data collection and analyses methods (compare with Phase 4 in Guba and Lincoln's (1998) description of the qualitative research process). This will be done in relation to the first four action research phases of diagnosis, planning, action taking and evaluation, rather than in relation to the specific data source (for more information on some of the research programmes the reader is referred to APPENDIX 1). In section 3.3, I will briefly reflect upon what kind of theory it is possible to extract from this kind of a research process and outline the links between the research process and the findings (thus addressing Guba and Lincoln's (1998) Phase 5). In the next chapter I will then describe the cases and present the within case analyses, that is, provide the empirical material *per se* for this thesis.

3.2 Methods of data collection and analysis

3.2.1 Pre-understanding

My almost two year long working experience from the power systems industry can be seen as the starting point for this thesis. This included the participation in the site work of two decentralised power plant projects (for more information, see Hellström, 2002). Since these deliveries can be characterised as highly modular, they have indeed served to enhance my pre-understanding of the studied topic. As for the first research question, this experience has provided an interesting installation point of view to modularity. The learning in relation to the second research question concerns the freedom to act that the modularised delivery permits in terms of project (or site) management. These viewpoints have been thoroughly described by especially Lindahl (2003).

3.2.2 Diagnosis

The research set-up in both cases included industry representatives from different parts of the value chain. In the ship case ship-yards, engineering companies, equipment suppliers, turnkey contractors, auditors and ship owners participated in the research. The diagnosis of the energy case, in turn, was built around a company consortium consisting of two equipment suppliers, one engineering firm, one systems integrator, one construction firm and one operator (energy company) as depicted in Figure 3-3. In addition, a research project surveying customers regarding their plants (boiler technology) constitutes part of the overall diagnosis of the energy case.

Not only major parts of the two value chains were represented. Also different parts of the systemic product under scrutiny were covered. In the ship case representatives for both traditional ship systems such as power production and modern demands such as hotel functions participated in the research programmes. Although the energy case was built around a certain technology, reciprocating engines, the research focused on issues of distributed and decentralised energy systems in general.

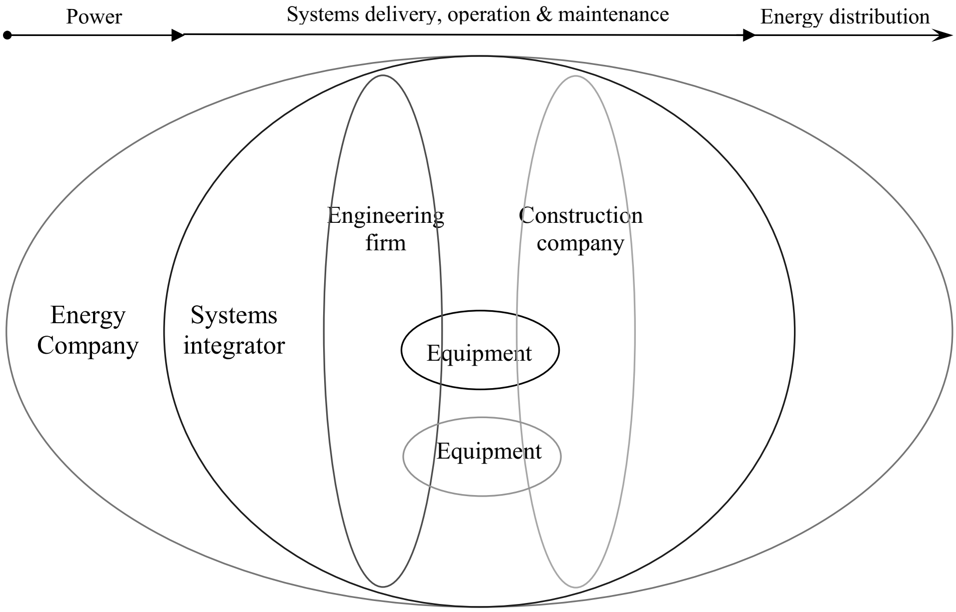


Figure 3-3 The positioning of the participating parties in the DENSY-project (for more information, see Hellström et al., 2005)

The specific objectives of the research programmes that the cases studies are based on are slightly different. Basically though, the common denominator has been the interest in creating a more 'modular' industry structure. Consequently, modularity has been one starting point for the surveys initially made. For the diagnosis various analyses of the current state of the value chain were prepared in both cases. The analyses followed a basic pattern where my research colleagues and I collected data, made rough analyses of it and presented the results at works shops or meetings where the participating companies took part in the interpretation of the results. Through such a 'falsification process' (see section 1.4.4) the analyses were either fine-tuned or the results rejected. The data was mainly collected through interviews and 'quick surveys', but also to some degree through e.g. participant observation. For a more detailed account on the methods used refer to APPENDIX 1. To some central parts information on method is given in chapter 4 along with the presentation of the case analyses.

Once an overall diagnosis had been reached action planning has followed. It has, however, in both cases been done in co-operation with concerned parties. Sometimes the groups have even wanted to specify the diagnosis with other complementary analyses. This way the process has been iterative and the final diagnosis has rather evolved during action planning. For instance, the application of the DSM technique, cast new light on the diagnosis in addition to its action planning mission (compare with the idea of many smaller action research cycles mentioned above). Underpinning the planning was a need for understanding, visualising and structuring the big systemic products and their delivery processes as wholes. Here we turned to the academic literature on modularity and project management. As a result of the planning process it was concluded in both cases that the design structure matrix (DSM) technique was an appropriate tool for our purpose. The DSM method is a product and project modelling tool and has briefly been described in section 2.3.2. In the next section I will describe why we ended up using the DSM and how it can be applied.

3.2.3 Action planning: applying the DSM-method

An essential element of the process of supporting industries in 'going modular' is the application of some kind of a modularisation method. In section 2.3 some such methods were presented. The choice of method is an intricate issue and does not go without arguments. Interestingly though, in a study on the application of three of the methods (the MIM (Erixon, 1998), the DSM (Steward, 1981; Pimmler and Eppinger, 1994) and Stone's (2000) "heuristic approach") to a real world case, Hölttä (2004) found that all three methods yielded different suggestions on how to modularise the product. In this study, the DSM-method was chosen due to its suitability for systematically analysing product-process structures, in addition to some other advantages it has in comparison to the other methods presented in section 2.3. As it starts from the product architecture it immediately addresses the first modularity criterion of independence. It is also a robust tool that allows us to consider various levels in the product hierarchy and thus suits large systemic products well. Moreover, it does not require an extensive set of available data on different design solutions but is capable of visualising the product (or project) structure, thus constituting a good tool for workshops and group decision making. It is also a flexible tool that can be used in many different ways (McCord and Eppinger, 1993; Pimmler and Eppinger, 1994; Eppinger, 1997; 2001; Sosa *et al.*, 2003). Most of all, it enables us to consider product and process architectures at the same time.

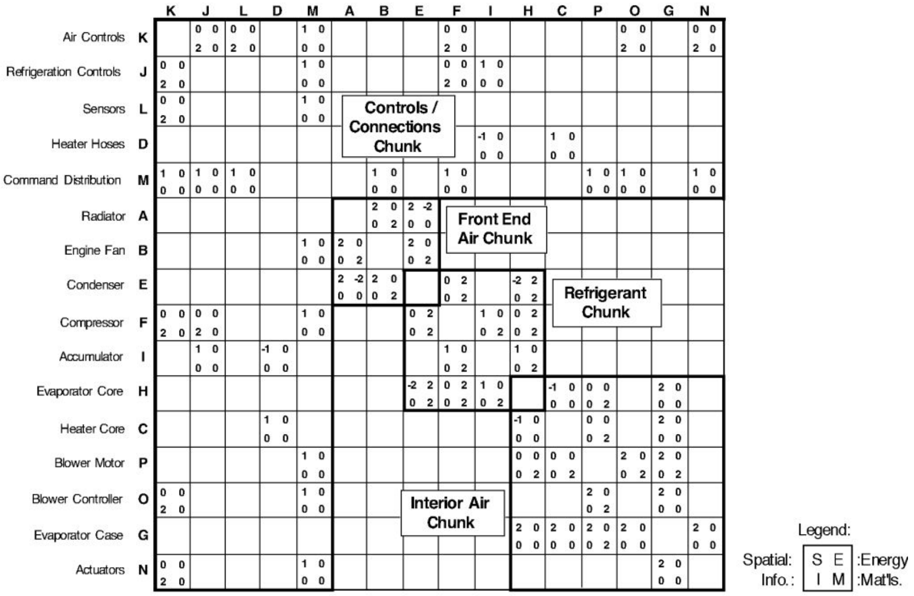
In section 2.3.2 I described the main idea and the application of the DSM method. Here I will describe the technique from a practical and methodological point of view and in general how it has been applied in this thesis work. The account of the method follows Eppinger and his colleague's description and use of the method (Pimmler and Eppinger, 1994; Eppinger, 1997; 2001; Sosa *et al.*, 2003). The case-specific applications are described together with the case analysis in sections 4.1.4 and 4.2.4.

The DSM-method consists of three major steps: the decomposition of the system into smaller units, the recording of the interdependencies between these units and finally the rearrangement of them (Pimmler and Eppinger, 1994).

- Decomposition can be done for different domains, e.g. according to function, (physical) building block or task breakdown, depending on the purpose of the analysis. The task breakdown will naturally be done when process structures are being analysed. When decomposing, one also has to decide at what level it will be done; for products: the sub-system, module, component, part or any other level.
- The recording of the interdependencies is done by 'measuring' the unit's relation to, or dependence on, the other units. This is systematically done for all units, one at a time. For product dependencies typically four or five different kinds of physical dependencies are considered: structural, spatial, material flow, energy transfer and signalling (Pimmler and Eppinger, 1994). Each kind of dependence can then be ranked (i.e. 'measured'), for instance on a five-point scale from 2 to -2. Process dependencies, in turn, are typically recorded as the frequency of information exchange between teams or other organisational groups engaged in the creation of the product. A scale ranging from e.g. quarterly to daily information exchange can be used. Finally, the results are mapped in a 'system decomposition versus system decomposition' matrix. Recording the interdependencies between the units in a system constitutes a big data collection effort. For the product matrix it is a straightforward process and the measurement can be done rather objectively, since the dependencies follow from physical relationships in the product. In the process matrix the interdependences obtain a more subjective character as it mainly reflects perceived rather than 'real' information need. (Interviews with) Design engineers or the like constitute the main data source in each case.
- The filled in DSMs can be analysed using heuristics or algorithms developed for the specific purpose. In both cases a range of different criteria can be applied such as independence and information axioms, strategic positions or anticipated technology development. Whatever the criteria and the order of their application, the basic idea is, in the case of the product matrix, to cluster the units of the system into larger, independent wholes, that is 'modules', and, in the case of the process matrix, to re-sequence the tasks of the project in a more 'logical' order in order to speed up the project.

In another variant of the method specifically developed for analysing the relation between product and process/organisation structures, the third step includes the comparison and alignment of the two structures to each other. In such an analysis the product structure could be seen as an analysis criterion for the process matrix. (Sosa *et al.*, 2003) Potential "misalignment" between the two structures could then be further analysed (Sosa *et al.*, 2004).

A filled in and ready-clustered DSM can be seen in Figure 3-4.



		K	J	L	D	M	A	B	E	F	I	H	C	P	O	G	N
Air Controls	K		0 0 2 0	0 0 2 0		1 0 0 0				0 0 2 0					0 0 2 0		0 0 2 0
Refrigeration Controls	J	0 0 2 0				1 0 0 0				0 0 2 0	1 0 0 0						
Sensors	L	0 0 2 0				1 0 0 0											
Heater Hoses	D										-1 0 0 0		1 0 0 0				
Command Distribution	M	1 0 0 0	1 0 0 0	1 0 0 0				1 0 0 0		1 0 0 0				1 0 0 0	1 0 0 0		1 0 0 0
Radiator	A							2 0 0 2	2 -2 0 0								
Engine Fan	B					1 0 0 0	2 0 0 2		2 0 0 2								
Condenser	E						2 -2 0 0	2 0 0 2		0 2 0 2		-2 2 0 2					
Compressor	F	0 0 2 0	0 0 2 0			1 0 0 0			0 2 0 2		1 0 0 2	0 2 0 2					
Accumulator	I		1 0 0 0		-1 0 0 0					1 0 0 2		1 0 0 2					
Evaporator Core	H								-2 2 0 2	0 2 0 2	1 0 0 2		-1 0 0 0	0 0 0 2		2 0 0 0	
Heater Core	C				1 0 0 0							-1 0 0 0		0 0 0 2		2 0 0 0	
Blower Motor	P					1 0 0 0						0 0 0 2	0 0 0 2		2 0 0 2	2 0 0 2	
Blower Controller	O	0 0 2 0				1 0 0 0								2 0 0 2		2 0 0 0	
Evaporator Case	G											2 0 0 0	2 0 0 0	2 0 0 2	2 0 0 0		2 0 0 0
Actuators	N	0 0 2 0				1 0 0 0										2 0 0 0	

Legend:
Spatial: S E :Energy
Info.: I M :Mat'ls.

Figure 3-4 An example DSM from a auto engine case (Eppinger, 1997: 203)

All the DSM-studies included in addition to the filled in matrices also other interviews, introductory meetings and workshops for further analysis and interpretation of the results. My role in these studies was to participate in the data collection and the analysis of the DSMs. I also participated in the meetings and the workshops.

3.2.4 Action taking and evaluation

After the DSM studies were done, they partly constituted the base for going further. My knowledge of that implementation phase stems from discussions with concerned parties (such as company representatives and my research colleagues), and participation in work shops and seminars where the results (achieved so far) and the status of further actions have been presented. By observing which parts of the research results (from the diagnoses and action planning phase) are embraced and taken further (and which are not), one is able to draw some conclusions as to the validity, or rather, trustworthiness and credibility (Guba, 1981; Lincoln and Guba, 1985; Guba and Lincoln, 1989) of the results. Again, a parallel to Popperian falsification can be made: if the results are not taken further they can be considered reject (with some caution, of course), whereas if they are, one can consider them to have successfully passed the falsification process. At the same time this falsification process partly corresponds to the evaluation phase of action research.

3.3 Interpretation and theory building

In accordance with the action and clinical research 'norm' the analysis and interpretation of the results has been done together with the research object (thus making it as much a subject; cf. section 3.2). As one of the starting points for this thesis has been to address practical problems, it is worthwhile pinpointing that the relevance of it has already partly been achieved through my engagement in the applied research projects Here, a parallel to Guba and Lincoln (1998) and their concepts of "catalytic and tactical authenticity" can be made. Catalytic (stimulating action) and tactical (empowering action) authenticity is according to them alternative quality criteria for qualitative (or more specifically, naturalistic) research. Whereas the stimuli to act might have originated from the very nature of the economic/business activities at hand, some ambiguity as to what to do and how to do what has prevailed. I do not claim that this thesis would have completely resolved this issue, but I do know that it actually has stimulated further action by giving the practitioners an idea of a possibly more "desirable future" and by inventing "ways of bringing it about" (quoting Ackoff, 1979: 103).

The typical problem with action research is, however, that it often results in much action but little research or vice versa (as quoted in Foster, 1972; Dickens and Watkins, 1999). Now then the results have to be shaped into a scientifically relevant contribution. As a guidance for the treatment of (processual) case studies Pettigrew (1990; 1997) describes a path of four forms of case study outputs along an evolutionary time line: analytical category, diagnostic case, interpretative/theoretical case and meta level analysis of cases. This is important, since it gives more opportunities for the use of the material, than simply studying and evaluating the impact of a certain prescription (which is typically assumed as the way action research is done). For instance my research is also concerned with the specific phenomenon of modularity (in addition to studying an action/a change process *per se*. The phenomenon is targeted through following research questions that were posed in the first chapter:

Q1) What is a 'good module' in projects?

Q2) How does modularity change the delivery process?

As to the nature of the research, research question Q1) attempts a more descriptive answer, whereas Q2) deserves a more normative one. This distinction is not, however, very clear-cut.

In line with Figure 3-1 the interpretative element is most of all present in the discussion and cross analysis of the two cases. This, in combination with the vast body of literature reviewed in chapter 2, enables the construction of the interpretative/theoretical case that Pettigrew (1990; 1997) calls for. Such an operation might also benefit from focusing the research problem into some more specific research questions. Even though cross case analyses are made and some effort is seen to make the cases more comparable, in the end the cases should rather be seen as complementary. It also ought to be remembered that the purpose of this study is not to draw statistical-like generalisations *per se* from the two cases in order to, for example, further be able to establish definite causal relationships, but to seek for a better understanding of the phenomenon of modularity and its applicability in different situations. Thus, differences between the cases will be as interesting as similarities.

Then turning the focus to the research questions the argumentation will proceed as follows. Before applying the questions to the material, I will provide a short background of respective industry. When asking what a 'good module' is a good starting point will be looking at how modularity is *de facto* perceived today. Presumably this will give an indication of some important characteristics of modularity. In order to go further and create something new, however, a new perspective has to be searched for. With regards to the definition of modularity I will thus ask what benefits the companies are looking for by going modular and how the modules are perceived in a life cycle context. Further on, function-to-structure criteria will be applied to the respective products using the DSM. After that, the life cycle criteria will be explored using the same DSM on the information structure of the projects.

Eventually, all the particular analyses, diagnoses and actions described in chapter 4 will also be analysed and interpreted at another, more abstract and theoretical level in chapter 5, rather than merely compared across the cases.

3.4 Quality criteria for non-positivistic research

It is obvious that different inquiry paradigms (see section 1.4.2) cannot be evaluated on the basis of same criteria (Susman and Evered, 1978; Guba and Lincoln, 1998). Internal and external validity, reliability and objectivity are commonly agreed as criteria for judging so called positivist science (see e.g. Bryman, 2001). Perhaps due to its heterogeneity a similar set of widely applied criteria has not been established in 'qualitative' research. Generally speaking, action research studies, as most other 'qualitative' research, can base its legitimacy as science in philosophical traditions such as pragmatism, hermeneutics and phenomenology (Susman and Evered, 1978). As for more specific criteria for evaluating research in these traditions, Guba and Lincoln's (Guba, 1981; Lincoln and Guba, 1985; Guba and Lincoln, 1989) two sets of "trustworthiness" and "authenticity" criteria for naturalistic research appear to be among the more referenced (see e.g. Tikkanen, 1997; Guba and Lincoln, 1998; Bryman, 2001). Trustworthiness corresponds to the four quality criteria of positivism and is generally not considered to fully succeed in escaping the "iron cage" and addressing the differences in the different paradigms (Tikkanen, 1997; Guba and Lincoln, 1998). Therefore the set of "authenticity" criteria has been added. I will use parts of these criteria to briefly reflect on the quality of this research in section 6.4.

4 CASE DESCRIPTIONS

In the second part of this chapter the two case studies are presented separately. The presentations, which alter between description and analysis, follow the same pattern in both cases: I begin with presenting the general industry characteristics in respective case, then move to the product-process characteristics in particular and further on to more specific diagnoses of the current status within the case consortia. This is followed by the application of the DSM-technique to the cases, which can be seen as a form of action planning in regard to the diagnosis made. Finally, the refined management process is described as its folds out in the light of modular entities identified through the DSM analysis.

4.1 The ship case

4.1.1 Industry characteristics

The current situation of the ship building industry is best understood by looking at the development of the industry over the later part of the 20th century. The European ship building industry has undergone a tremendous change during the past fifty years due to huge competitive pressures from the Far East. Shipping and ship building used to be closely related giving traditional shipping nations a large market share in ship building as well. In the 1960s these shipping nations started to lose market share especially to Japan. (Wijnolst and Wergeland, 1996/1997)) Since then the industry development can summarised in four key phases (First Marine International, 2003):

- 1960-1975: a period of high growth ending in an all time high output in 1975. The early 1970s saw the establishment of the South Korean ship building industry effectively commence.

- 1975-1980: a collapse in demand that led to severe over-capacity and a subsequent price slump. The regime of rationalisation and subsidies that still characterises the industry started during this period.
- 1980-1990: a period of sustained low output at around half of the peak level. Extensive rationalisation of capacity in Europe and Japan was undertaken, although some over-capacity remained.
- 1990- : a new era of high-growth thanks to fleet renewal and continued expansion of world trade. Due to the remaining over-capacity the demand increase has however not been accompanied with improved profitability of the world ship yards. In fact, due to considerable capacity expansion, especially in South Korea, prices fell on average by one third between 1991 and 2000.

Today one can speak of a truly global ship building industry (Wijnolst and Wergeland, 1996/1997). As a consequence the competitive edge has clearly shifted to the east. The industry is however very segmented. Due to the price slump in the late 1990s the EU yards have lost almost all their share in the volume sectors of bulk carriers and tankers and container ships (First Marine International, 2003). This situation has accelerated the trend of the EU shipyards to pursue a niche strategy towards building vessel types of higher technological sophistication and complexity requiring specialised know-how (Andritsos and Perez-Prat, 2000; First Marine International, 2003). Such vessel types include the luxury cruise ships that this case study focuses on.

4.1.2 Product and process characteristics

The luxury cruise vessel industry has emerged in response to the demand for sailing for enjoyment instead of merely moving passengers from one place to another. Consequently these ships can be described as floating holiday villages offering services such as swimming pools, restaurants, bars, discos, gymnasiums, casinos etc. Not only is luxurious outfitting important, special attention is also paid to reduction of noise and vibration. Moreover, the machinery requirements typically include demand for both high speed and good manoeuvrability, that is, powerful engines in combination with controllable pitch propellers and thrusters. (Wijnolst and Wergeland, 1996/1997) As we can see, cruise ship systems can be divided into the hotel function (cabins, catering etc) and the ship function (machinery, air water and sewage, HVAC etc) (Levander and Sillanpää, 2000).

Arguably, cruise vessels are amongst the most complex and technologically sophisticated products produced by any industry (First Marine International, 2003). For example, the worlds largest cruise ship, a Freedom class vessel under construction at the Turku ship yard in Finland, boards a maximum of 5740 persons. To serve the needs of these people some 3500km of electrical cables, 160 km of pipe and 60.000 m^2 of carpet have to be laid. The vessel is furthermore self-sufficient on power, and produces its drinking water and cleans its waste itself. As a result, building the ship requires some 3000 man-years of work and costs some 600 million euros. (Jurvelin, 2005)

In terms of ship building the cruise segment differs from the volume segments specifically on two major points. First, the traditional importance of shaping and assembling steel has diminished in favour of a greater focus on outfitting. Consequently the outfitting work on a modern cruise vessel can amount to some 80% of the total construction work; the steel work representing the remaining 20%. Second, the design, planning and management activities become more important and may even account for more than 10% of the total project cost. (Andritsos and Perez-Prat, 2000)

Basically, ship building can be divided into two major processes: information and production processes (Andritsos and Perez-Prat, 2000). The information processes include foremost the design of the ship, but also several other information-intensive activities related to planning and coordinating the production of the ship. These processes are typically sub-divided along with the three design phases. In the first, pre-contractual phase feasibility studies are carried out and the so called project design (also called concept design or pre-design) is prepared. This includes specifications, arrangement drawings, principal system diagrams and descriptions, architect specification and documents etc. The next, basic design phase includes, in addition to the basic design itself (termed “class design” by Andrtisos and Perez-Prat (2000)), activities such as coordination engineering, procurement handling, master scheduling and building procedure planning. The third and final phase entails in addition to detailed design, work planning and preparation. (Kanerva *et al.*, 1999)

The production processes essentially consist of transforming raw material, such as steel, to ship structures. The transformation process proceeds from cut steel plates to 2D blocks, from 2D to 3D blocks, which then are further assembled to grand blocks. These grand blocks finally constitute the erection units for the ship itself. In addition to the steel work and block assembly cruise vessel construction include lots of outfitting work as already noted above. In modern ship building there is a trend to move the outfitting work to earlier phases of the construction process. Hence the aim is to pre-outfit the 3D and grand blocks as far as possible before installing them onto the ship. There is also a trend towards prefabricating supports, pipes and machinery units as much as possible before installing them onto the ship. In addition much of the blasting and painting is increasingly moved out from the ships. After the last finishing and outfitting works done on board, the production process ends with commissioning and sea trials. In addition to the core production processes, support processes such as transportation and materials handling as well as dimensional control and inspection are vital parts of production. (Andritsos and Perez-Prat, 2000) A schematic picture of the entire production process is shown in Figure 4-1.

Although here presented separately, the production and information processes are by nature integrated as shown in Figure 4-2. The integration of production and information processes is not only highly facilitated by the use of CAD/CAE-systems, but nowadays these systems are ever more assuming the role of the integrator between the information and production processes (Andritsos and Perez-Prat, 2000).

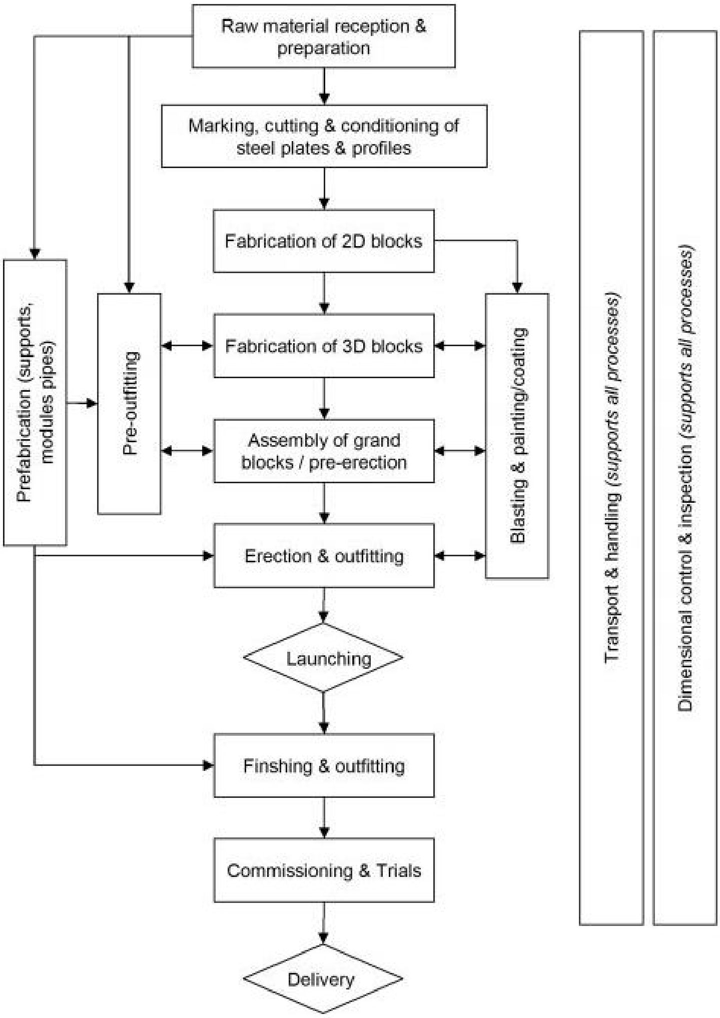


Figure 4-1 The production process of a ship project (Andritsos and Perez-Prat, 2000: 32)

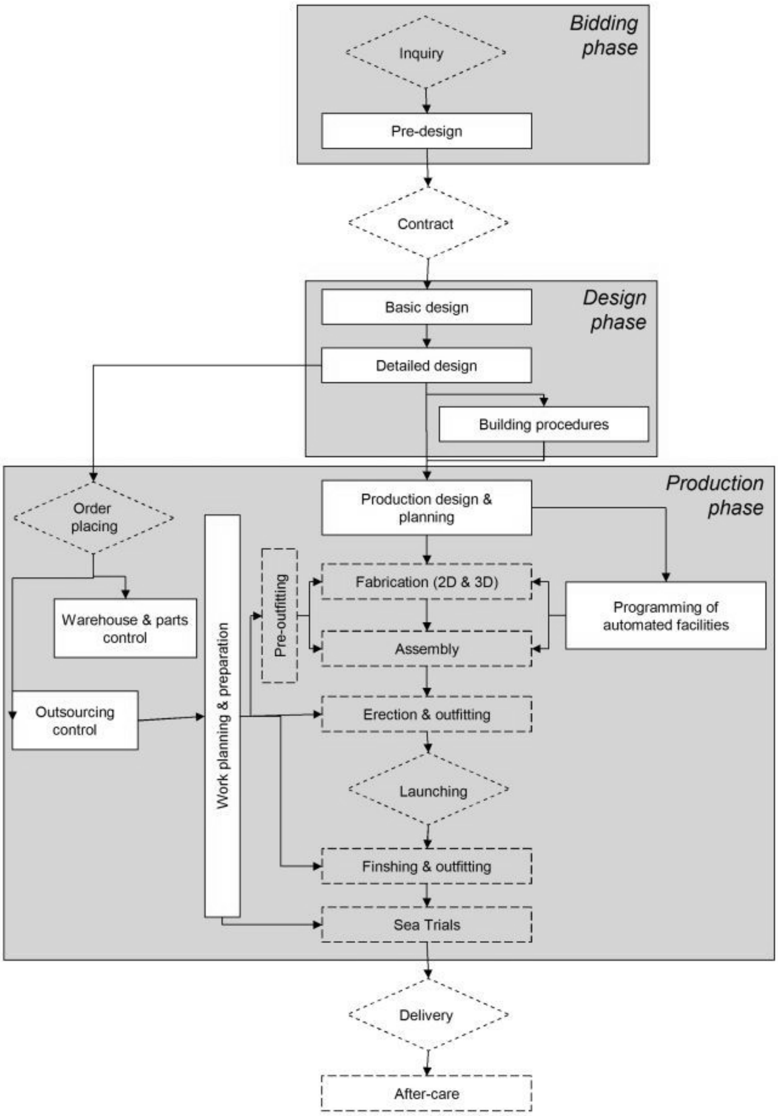


Figure 4-2 The information processes of a ship project (Andritsos and Perez-Prat, 2000: 34)

Since the 1980s the production management has clearly moved toward an increased focus on materials management, thus leaving two major phases under the control of the ship builder, i.e. “make or buy” and “install” (Taiminen, 2000). The procurement process has consequently become an important process, which cuts across both production and information processes. The following types of subcontracting are commonly used at the yards (Rotkirch, 2000):

- Turnkey delivery (full responsibility from design to commissioning)
- Design
- Manufacturing
- Installation
- Other works and services

In practice, these types might be combined in different constellations. Most important is however that the information processes, notably the design, proceeds in a manner that supports the production process (Holmström, 2000).

Traditionally outfitting work on ships was done on a system basis. However, when moving towards increased pre-outfitting of blocks this approach had to give way for area or section based outfitting, since many systems cut across block boundaries. The work was then divided according to profession or field, which was soon found to cause some disturbances in the ship building process. (Taiminen, 2000). Despite the changes in the product and production towards shifting the focus from steel works to outfitting and finishing activities, the traditional concept of ship building largely prevails on the European ship yards (Andritsos and Perez-Prat, 2000). However, there are some signs of a change in the way of working. To avoid the problems and bridge the gaps between professional groups that the field-specific way of organising the work caused, the team-based approach was introduced in the 1990s, which gave inter-disciplinary teams responsibility for certain areas or systems (Holmström, 2000; Taiminen, 2000). One related, current trend in this regard is the more extensive use of subcontractors, which are ever more expected to assume turnkey responsibility of whole systems or sections. The corresponding business concept for the ship builder is labelled “assembly yard”. (Turkki, 1997; Andritsos and Perez-Prat, 2000; Toivonen, 2000) The use of subcontractors is seen as a means for managing the situation where certain demanding outfitting work requires highly skilled personnel for limited periods of time (Andritsos and Perez-Prat, 2000). The use of subcontractors is furthermore expected to shorten lead times (Turkki, 1997), although this arguably also is a consequence of moving outfitting work out from the ship. The move from the traditional field-specific (mechanical, electrical etc) sub-contracting to turnkey deliveries however constitutes a big institutional change for both ship yards and sub-contractors, which especially requires increased attention on interfaces (Toivonen, 2000).

4.1.3 Product-process diagnosis

Modularity is by no means a new concept in ship building. Modular outfitting, that is the use of pre-outfitted units of a specific size, have been developed at ship yards since the mid-1970s (Häkkinen, 1993). Quite often the terms "module" and "machinery unit[1]" are used interchangeably. A machinery unit is, broadly speaking, understood as various mechanical equipment forming a functional whole that is preassembled on the same platform before being lifted on the ship. During the 1980s the idea to assemble so called "macro modules" (Häkkinen, 1993) or "large machinery space modules" from smaller machinery units was launched (Holmström, 2000). The rationale behind all such modules is the shortening of the outfitting time, the minimisation of the work done on-board, the reduction of crossing points between different disciplines as well as the clarification of the design work in connection with outfitting (Häkkinen, 1993). As we have seen, such a strategy of moving the work from the ship to the workshops has proven quite successful. According to some studies outfitting work inside the hull requires four times the working hours that it takes in a workshop. The corresponding figure for outfitting work done on a block is 1.5 and on a sub-block 1.2. (Häkkinen, 1993). However, at times preassembling has become an end in itself and for example the function aspect has gained lower priority. Still, the situation when modules contain an embedded function that can be pretested before installation is seen as an even more useful characteristic by some shipyard representatives.

Machinery has clearly been the most common objective for modularisation in ship building. Still, there are both on-going attempts and existing solutions for creating modules in other areas as well. For instance, a solution for passenger cabin-modules has been around since the 1980s. Such cabins can be prefabricated in workshops and lifted directly on-board the ship. The rationale is thus quite the same as for the machinery modules.

The importance of the preassembly aspect of modules can also be sensed from Figure 4-3, which shows the results from a survey concerning modularity among representatives from some ship yards[2]. The survey was conducted within the

---

[1] As corresponding to the Finnish word "koneikko".

[2] The results in the figure are not tested for statistical significance. Admittedly the limited sample of 14 respondents is not enough for far reaching conclusions, but however fulfils the purpose of being indicative.

Intership programme (see section 3.1 and refer to project S-2 in Table 3-a). The 14 respondents were evenly distributed between strategic, operational and development functions at the yards.

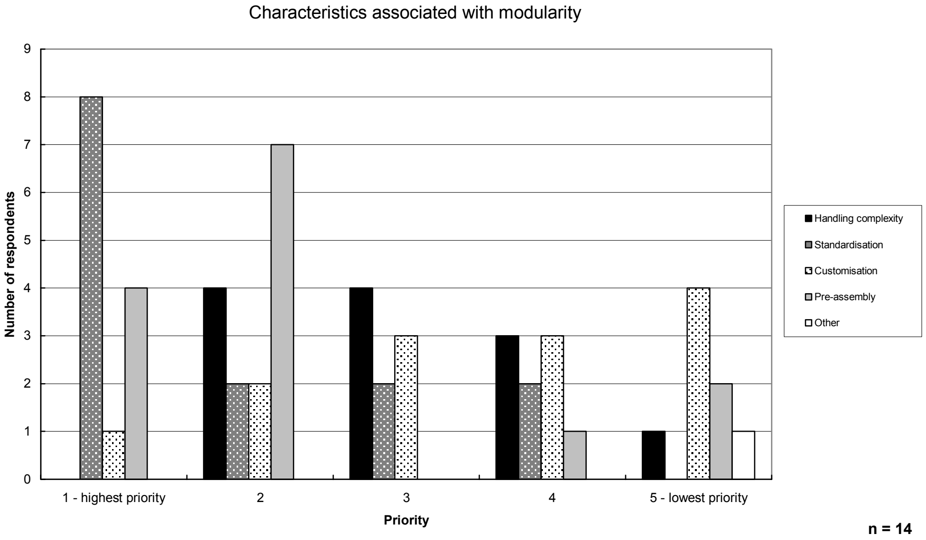


Figure 4-3 Frequency distribution of the priority between modularity drivers (for more information, see Hellström and Wikström, 2004)

Generally speaking, the figure indicates a production-oriented view of modularity in ship building, as both standardisation and preassembly are ranked high. In contrast there seems to be little belief in using modularity for customisation and handling complexity, which in many other industries are strong drivers behind modularity as we have seen in section 2.2 of this thesis. And although standardisation is seen as important, in practice only few modules have been developed that remain unchanged from ship project to project. Thus expected economies of scale are seldom realized. Instead, a variety of project-specific modules are developed, which furthermore often contain a high amount of errors like prototypes typically do. Presumably, partly due to these reasons modularisation is often met with scepticism and even seen as something negative. The failure to standardise ship systems is obvious when looking at the distribution of used time between the different design phases. According to a recent report within the MERIKE programme (see section 3.1; project S-3 in Table 3-a) concerning the production and management of technical information in traditional ship projects typically 2-3% of the total design hours are used for project design, some 18% for basic design and up to 80% for detail design (Wikström *et al.*, 2004). Although the results are only indicative, the give us a good idea of where most of the design effort is used. The high share of detail design suggests that the use of tailor-made components/parts prevails.

As a consequence of the poor success in achieving economies of scale, also the expected time-cost-quality improvements that can be achieved through modularisation are comparatively small among shipyard representatives as seen in Figure 4-4 below. The Figure originates from the same Intership survey as discussed above (see Figure 4-3). For instance, lead time, which is given highest priority among the three dimensions (Figure 12), is expected to be reduced by only 15%. For comparison, in the paper machine industry a time reduction potential through standardisation and modularisation of more than 30% has been reported (Nilsson *et al.*, 1999). Another survey made within the Intership programme, now benchmarking against some land-based project suppliers, indicated that shipbuilders in general tend to regard the benefits of modularity more pessimistically than their colleagues on land (Hellström and Wikström, 2005a).

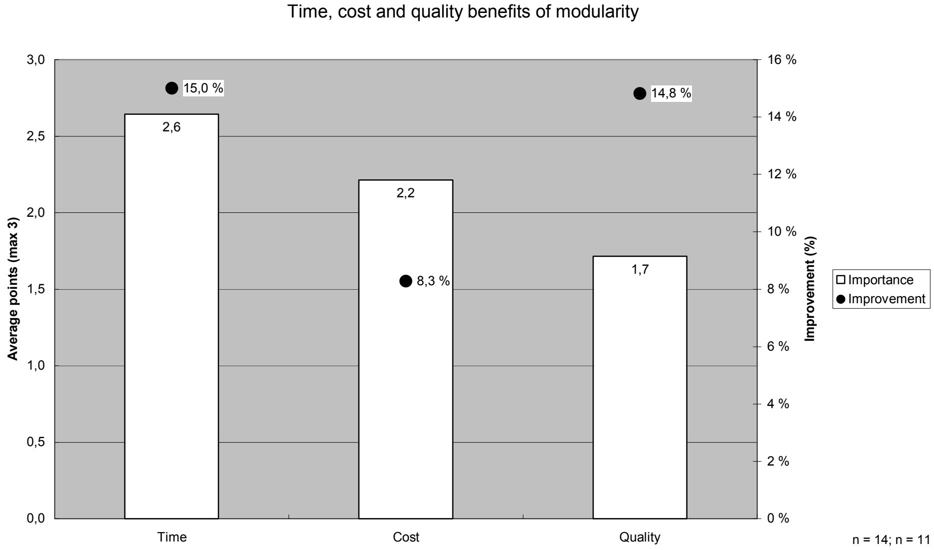


Figure 4-4 Average benefit priority score and average expected improvement (for more information, see Hellström and Wikström, 2004)

Another current problem in the design process, the allocation of time for different design tasks, is also discussed in the report by Wikström *et al.* (2004) (see two paragraphs above). Interestingly, only a small portion of time is used for handling interfaces in relation to intra-task design, although specifically the interfaces are generally perceived as a major problem. The problems with the interfaces can be interpreted as a symptom of the fact that so little time is used for interface engineering tasks. This, in turn, can also be seen as a consequence of the lack of standardisation of ship systems and the high proportion of detail design.

When a module or machinery unit has been developed it is typically preassembled by a supplier in a workshop outside the ship or even outside the ship yard. Consequently, it is also there the 'mass' production of modules is expected to take place. As already discussed in section 4.1.2 the trend in ship building is to move towards more turnkey deliveries where some of such module makers would assume a larger responsibility and provide whole systems or areas from detail design to installation. As turnkey-contracting has proven successful also in the long run, it is now also seen as means for achieving a higher degree of modularity. The idea is that selected first tier suppliers by being assigned and assuming responsibility of larger functional and isolated wholes would be better off and find higher incentives to develop repeatable product solutions. Thereby dominant designs for certain ship systems could be attained.

In this kind of arrangement more effort should be put on defining the interfaces in conceptual or project design, whereas detail design should be brought to a minimum through the development and use of standardised modules or modular sub-systems. In a way one could say that the systems are then being configured by 'mixing and matching' these 'modules'. Such configuration would then require that the interfacing parties can participate in the project design and define the "design rules", using Baldwin and Clark's (1997) terminology. Basically, this would mean participation in the sales process, which is also one of the central themes that Wikström *et al.* (2004) found in their investigation of the current state of the information process in ship building. However, the role of suppliers is generally looked at narrowly. From Figure 4-5 from the Intership survey we can see that among some shipyard representatives the sub-suppliers' role is mainly seen as production and installation, and, to a considerably smaller extent, innovation and maintenance. This is obviously something that has to change if the shipyards want to continue the trend towards becoming so called "assembly yards".

Figure 4-5 Frequency distribution of the sub-supplier's perceived role (for more information, see Hellström and Wikström, 2004)

The starting point for the diagnosis of the current situation within the Finnish ship-building industry made by Wikström *et al.* (2004) was the categorisation of technical information, the role of different players and the current way of working[1]. Based on 15 interviews in 14 companies, including ship-yards, engineering companies, equipment suppliers, turnkey contractors, auditors and ship owners, among others the following central themes were raised (including some of those already discussed above):

- Development of life-cycle thinking
- Conceptual design
- Standardised product solutions
- Common, harmonised-standardised way of working
- Interface clarification (process)

---

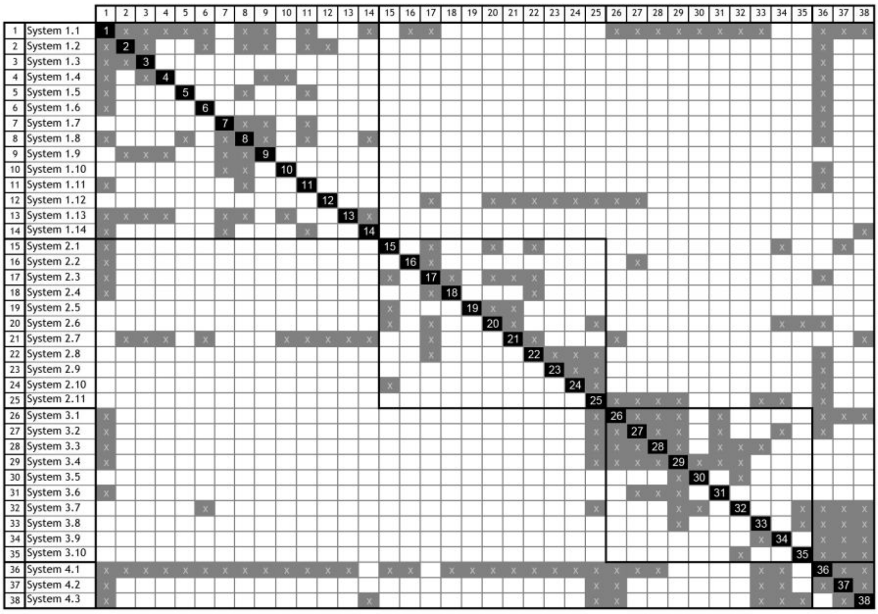
[1] This paragraph is based on Wikström, Westerholm and Toivola (2004) unless otherwise stated.

Larger functional wholes would also enable what is commonly called an 'information' or 'virtual module' in design, that is, the situation when most of the needed design interaction takes place within one organisation. Even if standard modules, in the building block meaning, were not possible to create, the information needed to create that 'module' resides in one place. The idea of modularity in design also goes well with the systems based design approach used at least in Finnish ship yards (Levander and Sillanpää, 2000). It does, however, not only concern design information, although this aspect has been emphasised so far. It also concerns information needed through out the life cycle of a ship (compare with the central themes listed above), first of all during the production. One could thus also extend the modularity concept to 'modularity in production', meaning that the 'module' also can be installed as independently as possible from other parts. In a ship, however, there are lots of interfaces between different installation teams and the need for coordination can hardly be eliminated. This requires especially two things, which also can be seen from list above. First, a common way of working is needed in order to ensure seamless interplay where different parties meet and have to cooperate. Second, for similar reasons project management skills are expected from the first tier suppliers, especially in terms of scheduling, so that common interfaces or milestones can be monitored and coordinated. In a way one could say that one wants to preserve the good things from the old centralised way of working, that is, the common working processes and combine it with the strengths of the new, decentralised way of working, that is, the creativity and drive for finding more efficient products and production processes, at least to the extent this can be better achieved in isolation.

4.1.4 Product structure analysis

In the report referenced above interfaces between different supply scopes in a ship were identified as one key element in developing the ship building process. It is quite natural to assume that such interfaces in some way or another stem from the interfaces in the product itself (see e.g. Sosa et al., 2003; 2004). As discussed in section 2.1, interfaces are also at the core of the concept definition of modularity. Thus, the product structure and the interfaces it exhibits is a reasonable starting point for any investigation on the 'excellence' of a module. As ship systems are so different I will for comparison analyse two quite different ship system areas (refer to projects S-4-7 in Table 3-a): the engine room and the cabin area (that is, one representing the traditional ship functions and another representing the hotel functions). As mentioned in section 3.2.4 this analysis is based on the design structure matrix (DSM) technique. Figure 4-6 and Figure 4-9 shows the so called component-based DSMs (or in this case rather the 'systems-based') for the engine room and the cabin area respectively. For graphical simplicity only the binary forms of the matrices are displayed, although four types of interface types were recorded (geometry (spatial/structural), material flow, electricity and information signal (automation)).

The engine room DSM is based on a system breakdown. Together with engineers from a firm specialised in ship design we decomposed the entire ship power system and related functions into 38 sub-systems. This was considered a suitable level of analysis. The sub-system interfaces or dependencies were then recorded in the matrix by the firm's engineers.

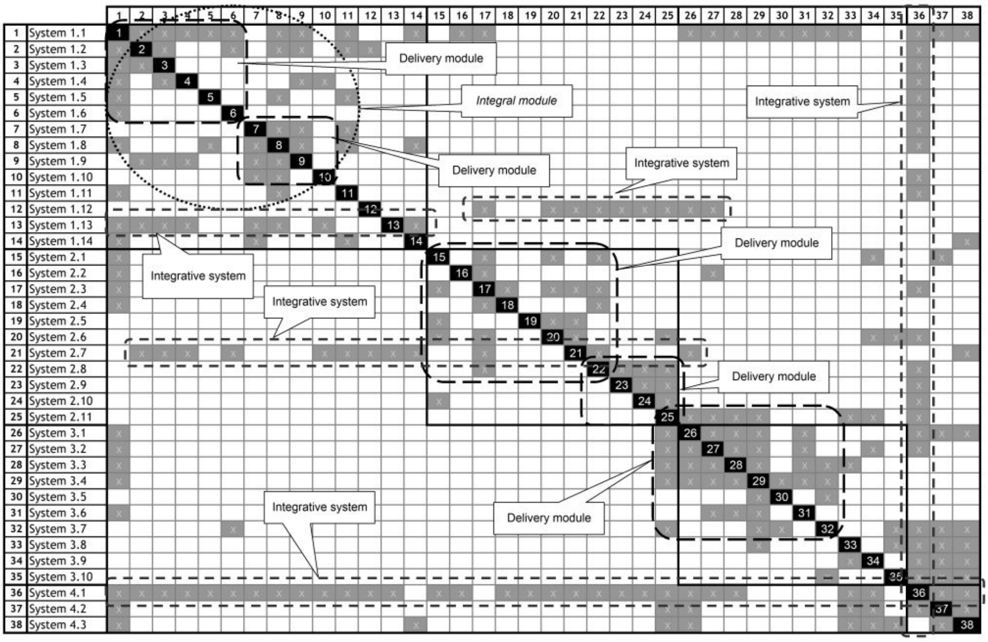


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1	System 1.1	1	x	x	x	x	x		x	x		x			x		x	x									x	x	x	x	x	x	x	x			x	x	x
2	System 1.2	x	2	x			x		x	x		x	x																								x		
3	System 1.3	x	x	3																																	x		
4	System 1.4	x		x	4					x	x																										x		
5	System 1.5	x				5			x			x																									x		
6	System 1.6	x					6																														x		
7	System 1.7							7	x	x		x																									x		
8	System 1.8	x				x		x	8	x		x			x																						x		
9	System 1.9		x	x	x			x	x	9																													
10	System 1.10							x	x		10																										x		
11	System 1.11	x							x			11																									x		
12	System 1.12												12					x			x	x	x	x	x	x	x	x											
13	System 1.13	x	x	x	x			x	x		x			13	x																								
14	System 1.14	x						x				x			14																								x
15	System 2.1	x														15		x			x		x												x			x	
16	System 2.2	x															16	x										x											
17	System 2.3	x														x		17	x		x	x	x														x		
18	System 2.4	x																x	18				x																
19	System 2.5															x				19	x	x																	
20	System 2.6															x		x			20	x				x									x	x	x		
21	System 2.7		x	x	x		x				x	x	x	x	x			x				21	x				x												x
22	System 2.8																	x					22	x	x	x											x		
23	System 2.9																							23	x	x											x		
24	System 2.10															x									24	x											x		
25	System 2.11																									25	x	x	x	x				x	x		x		
26	System 3.1	x																								x	26	x	x	x		x					x	x	x
27	System 3.2	x																								x	x	27	x	x		x			x		x		
28	System 3.3	x																								x	x	x	28	x		x	x	x					
29	System 3.4	x																								x	x	x	x	29	x	x	x						
30	System 3.5																													x	30		x						
31	System 3.6	x																										x	x	x		31							
32	System 3.7						x																			x				x	x		32			x	x	x	x
33	System 3.8																													x				33		x	x	x	x
34	System 3.9																																	x	34		x	x	x
35	System 3.10																																x			35	x	x	x
36	System 4.1	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x	x	x	x					x	x		36	x	x
37	System 4.2	x																								x	x							x	x		x	37	x
38	System 4.3	x													x											x	x							x	x	x		x	38

Copyright PBI Research Institute 2005

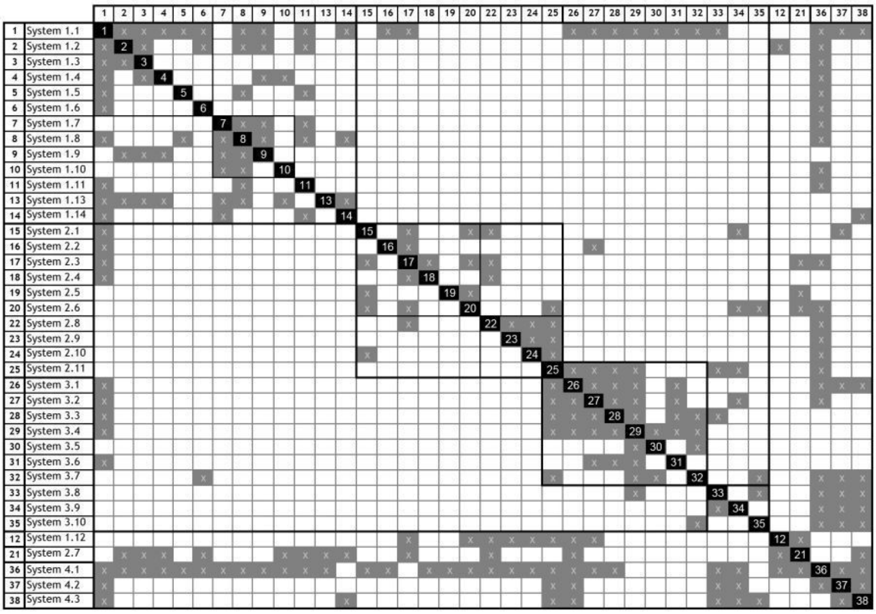
Figure 4-6 Product-DSM of ship engine room (for more information, see Wikström *et al.*, 2005)

As we can see from the figures the engine room exhibits a potential for a fairly modular system structure, but also that the area contains some fairly integrative systems (following the vocabulary used by Sosa *et al.* (2003)). In Figure 4-7 some modular and integrative system clusters have been identified. System 1.1 is intentionally not denoted "integrative", although it clearly shares interfaces with many other systems. This is because system 1.1, being the prime mover (typically a diesel engine or a gas turbine), is anyway to be seen as the core of the machinery space. System 1.1 furthermore shows particularly dense interaction with the other systems in system group 1. Thus I prefer to use the concept of "core system" after Tushman and Murmann (1998) for system 1.1 instead. This is indeed only a matter of terminology and definition, but the way we presented the analysis for the involved companies. Figure 4-8 then shows the same DSM where these clusters have been regrouped into modular and integrative wholes. The clustering has been cross checked by representatives from the engineering firm.



Copyright PBI Research Institute 2005

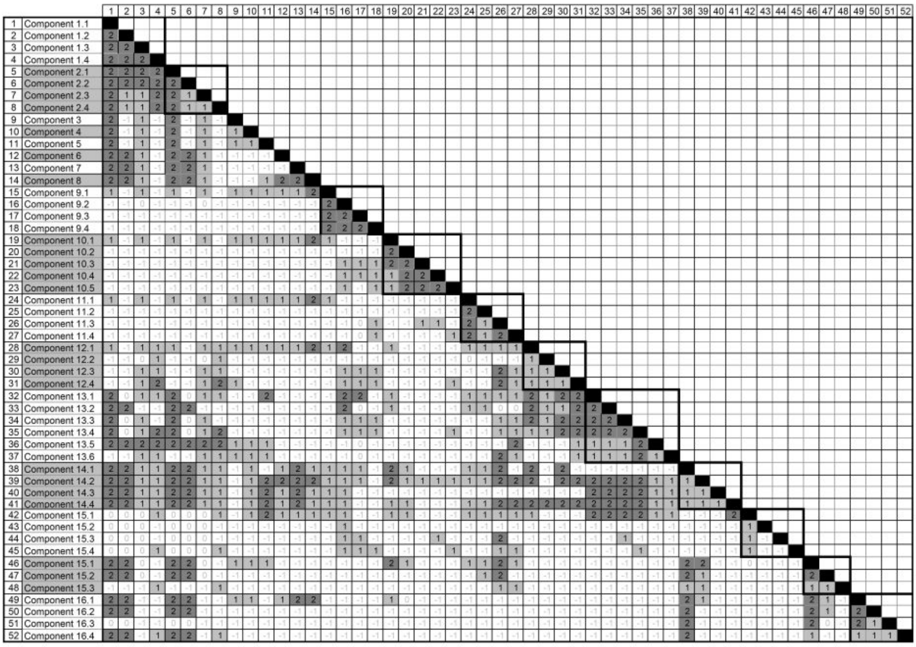
Figure 4-7 Modular and integrative wholes identified in the engine room (for more information, see Wikström *et al.*, 2005)



Copyright PBI Research Institute 2005

Figure 4-8 Re-structured DSM for the engine room (for more information, see Wikström *et al.*, 2005)

The cabin area DSM (Figure 4-9), in its turn, is rather based on a mix of structure and system breakdown. In addition, parts of the hull has been included in the breakdown as the cabin area is already physically in contact with the hull and furthermore cut across block boundaries. The DSM was developed together with representatives from both the cabin supplier and an engineering firm. A decomposition into 52 'elements' was considered suitable for the given purpose. The physical dependencies were recorded on scale from -2 to 2 for the same four dimensions as above in the engine room case. For graphical simplicity only the structural (geometry) dimension is shown in Figure 4-9. The colour indicates the strength of the dependencies (the darker the blue colour the stronger the dependency). For further simplicity only one way dependencies are recorded in this case, or rather no difference is made as to which way the dependency between two elements goes. This is of course a rough approximation, but the matrix still serves the purpose of being indicative.



Copyright PBI Research Institute 2005

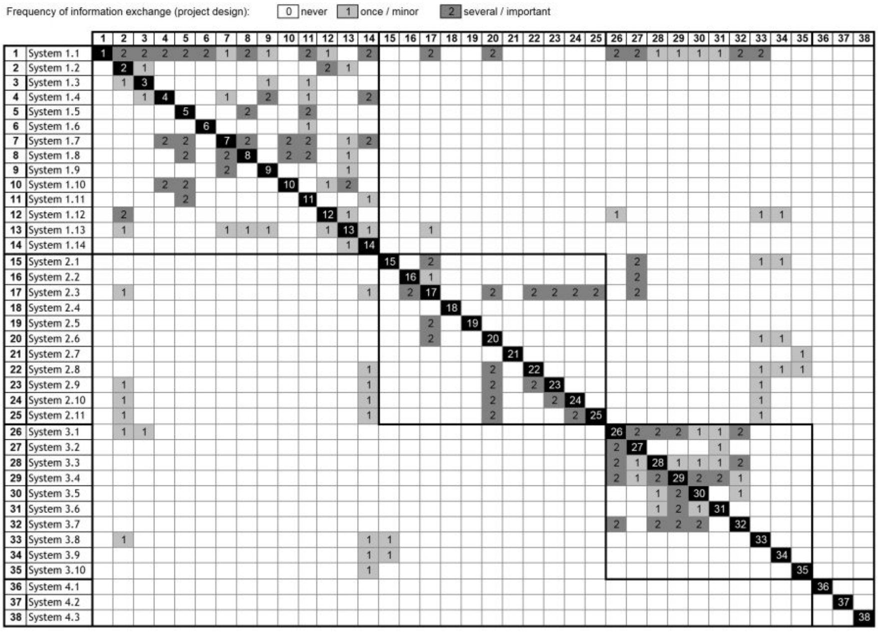
Figure 4-9 Product-DSM (structural interfaces) of the cabin area

Whereas modular systems fairly well can be identified in the engine room, the elements of the cabin area seem to be more integrated as a whole, at least considered from a structural viewpoint (in fact the other dependencies quite far follow the structural ones). This can probably be seen as characteristic for civil constructions. What still could be done here is to see whether all the product interfaces are translated to design interfaces in the design process DSM or whether this yields a more clear structure. From Figure 4-12 we can see that this is partly the case. I will further discuss this issue in the next section. The main conclusion as to the product structure of the cabin area is, however, that it is by nature an integrated whole (despite some fairly clear modules like the cabins themselves) and thus should be treated as one. From Figure 4-9 we can for instance see that the both corridors (components 13.1-6) and isolation (component 3) are highly integrated with the cabins (something that indeed is not really surprising). Based on this one could even argue that the cabin area as a whole should constitute one single scope of supply (except for the hull and some other 'intersecting systems'). This is in fact what happened in the studied case. Here we should remember, though, that the cabin area still does not really constitute a modular system with regards to the ship as a whole, among other reasons since the area is highly integrated with the hull. This in turn has some important implications for the management of the design and installation process as will be discussed in the next section.

4.1.5 Process structure analysis

After having investigated the issue of modularity in product (or system) architecture the natural thing to do, according to the framework, is to study the dependencies in the corresponding delivery processes, notably design and installation. Again I start with the engine room and then move on with some examples from the hotel function of a ship for comparison.

Starting with the project design of the ship engine room, we used the same system breakdown as in the product structure analysis. However, now we chose to record the dependencies according to frequency and importance of information exchange between the design teams or engineers that are responsible for designing the respective parts. The frequency and importance of the information was assessed on a three point scale, which can be seen in Figure 4-10 (above the matrix). The darker the blue colour, the higher the exchanged frequency (and the more important the information exchanged). As can be seen from the figure there are less dependences in the project design than in the product architecture (shown in Figure 4-6). What is even more is that the systems seem to be fairly independent and that there is an almost complete lack of integrative systems in this phase of a ship project. This should provide a good basis for taking the idea of sales configurators further (since project design can be defined as the design made before the ship contract is signed).

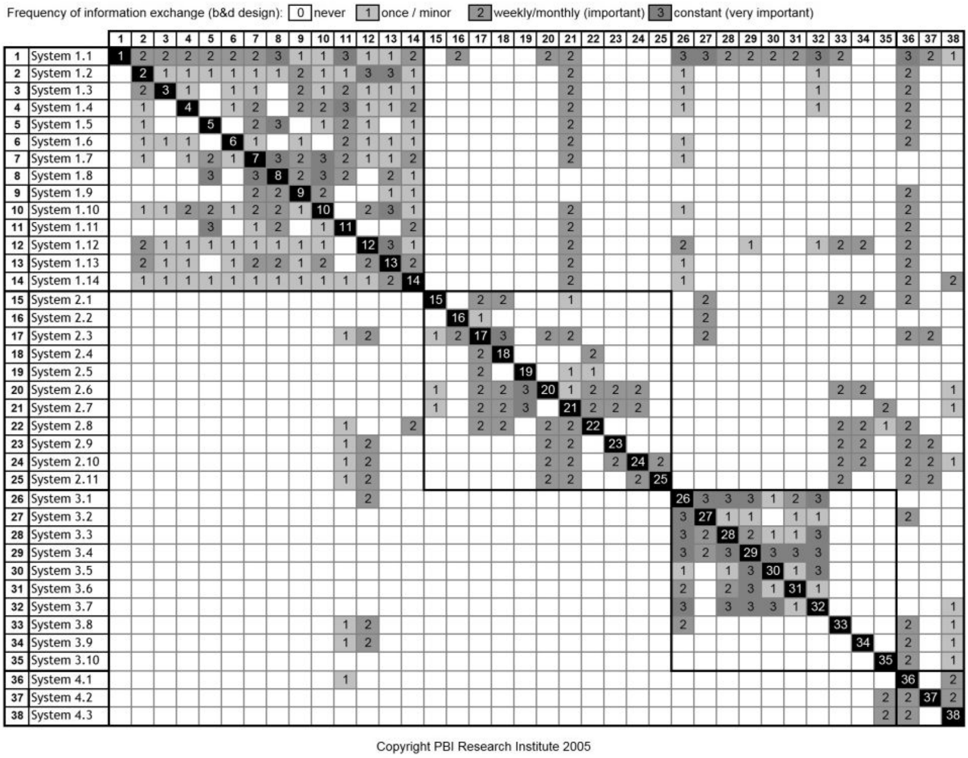


Frequency of information exchange (project design): 0 never 1 once / minor 2 several / important

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1	System 1.1	1	2	2	2	2	2	1	2	1		2	1		2			2			2						2	2	1	1	1	1	2	2					
2	System 1.2		2	1									2	1																									
3	System 1.3		1	3						1		1																											
4	System 1.4			1	4			1		2		1			2																								
5	System 1.5					5			2			2																											
6	System 1.6						6					1																											
7	System 1.7				2	2		7	2		2	2		1	2																								
8	System 1.8					2		2	8		2	2		1																									
9	System 1.9							2		9				1																									
10	System 1.10				2	2					10		1	2																									
11	System 1.11					2						11			1																								
12	System 1.12		2										12	1													1							1	1				
13	System 1.13		1					1	1	1			1	13	1			1																					
14	System 1.14													1	14																								
15	System 2.1															15		2										2						1	1				
16	System 2.2																16	1										2											
17	System 2.3		1												1		2	17			2		2	2	2	2		2											
18	System 2.4																		18																				
19	System 2.5																	2		19																			
20	System 2.6																	2			20													1	1				
21	System 2.7																					21														1			
22	System 2.8														1						2		22											1	1	1			
23	System 2.9		1												1						2		2	23										1					
24	System 2.10		1												1						2			2	24									1					
25	System 2.11		1												1						2				2	25								1					
26	System 3.1		1	1																							26	2	2	2	1	1	2						
27	System 3.2																										2	27				1							
28	System 3.3																										2	1	28	1	1	1	2						
29	System 3.4																										2	1	2	29	2	2	1						
30	System 3.5																												1	2	30		1						
31	System 3.6																												1	2	1	31							
32	System 3.7																										2		2	2	2		32						
33	System 3.8		1												1	1																		33					
34	System 3.9														1	1																			34				
35	System 3.10														1																					35			
36	System 4.1																																				36		
37	System 4.2																																					37	
38	System 4.3																																						38

Figure 4-10 Process-DSM of ship engine room (project design) (for more information, see Wikström *et al.*, 2005)

Next we recorded a combined DSM over both basic and detail design (Figure 4-11). Also in this case we used exactly the same breakdown (the original, not the re-arranged) and information exchange as the meter for dependency, however, now on a four point scale as can be seen from the legend in Figure 4-11 (above the matrix).



Frequency of information exchange (b&d design): 0 never 1 once / minor 2 weekly/monthly (important) 3 constant (very important)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1	System 1.1	1	2	2	2	2	2	2	3	1	1	3	1	1	2		2				2	2					3	3	2	2	2	2	3	2			3	2	1
2	System 1.2		2	1	1	1	1	1	1	2	1	1	3	3	1							2					1						1				2		
3	System 1.3		2	3	1		1	1		2	1	2	1	1	1							2					1						1				2		
4	System 1.4		1		4		1	2		2	2	3	1	1	2							2					1						1				2		
5	System 1.5		1			5		2	3		1	2	1		1							2															2		
6	System 1.6		1	1	1		6	1		1		2	1	1	1							2					1										2		
7	System 1.7		1		1	2	1	7	3	2	3	2	1	1	2							2					1												
8	System 1.8					3		3	8	2	3	2		2	1																								
9	System 1.9							2	2	9	2			1	1																						2		
10	System 1.10		1	1	2	2	1	2	2	1	10		2	3	1							2					1										2		
11	System 1.11					3		1	2		1	11			2							2															2		
12	System 1.12		2	1	1	1	1	1	1	1	1		12	3	1							2					2			1			1	2	2		2		
13	System 1.13		2	1	1		1	2	2	1	2		2	13	2							2					1										2		
14	System 1.14		1	1	1	1	1	1	1	1	1	1	1	2	14							2					1										2		2
15	System 2.1															15		2	2			1						2						2	2		2		
16	System 2.2																16	1										2											
17	System 2.3											1	2			1	2	17	3		2	2						2									2	2	
18	System 2.4																	2	18				2																
19	System 2.5																	2		19		1	1																
20	System 2.6															1		2	2	3	20	1	2	2	2									2	2				1
21	System 2.7															1		2	2	3		21	2	2	2											2			1
22	System 2.8											1			2			2	2		2	2	22											2	2	1	2		
23	System 2.9											1	2								2	2		23										2	2		2	2	
24	System 2.10											1	2								2	2		2	24	2								2	2		2	2	1
25	System 2.11											1	2								2	2			2	25								2			2	2	
26	System 3.1												2														26	3	3	3	1	2	3						
27	System 3.2																										3	27	1	1		1	1				2		
28	System 3.3																										3	2	28	2	1	1	3						
29	System 3.4																										3	2	3	29	3	3	3						
30	System 3.5																										1		1	3	30	1	3						
31	System 3.6																										2		2	3	1	31	1						
32	System 3.7																										3		3	3	3	1	32						1
33	System 3.8											1	2														2							33			2		1
34	System 3.9											1	2																						34		2		1
35	System 3.10																																			35	2		1
36	System 4.1											1																									36		2
37	System 4.2																																			2	2	37	2
38	System 4.3																																			2	2		38

Copyright PBI Research Institute 2005

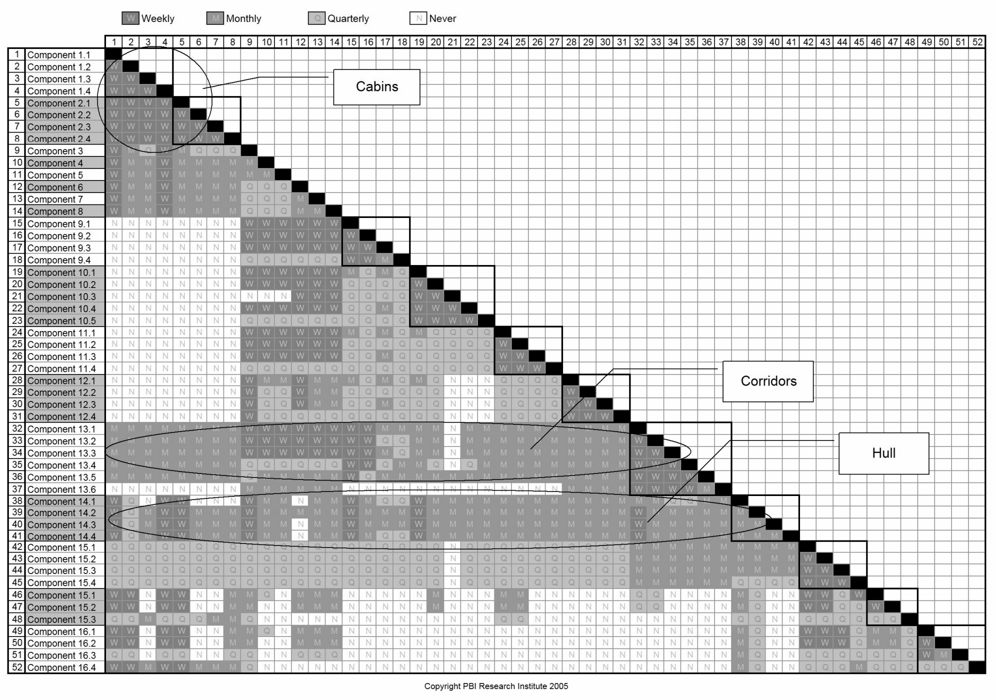
Figure 4-11 Process-DSM of ship engine room (basic & detail design) (for more information, see Wikström *et al.*, 2005)

There are some observations to be made from the above figure. First of all, we can see that the dependencies quite far follow those of the product architecture (Figure 4-6). This implies that at least from an information flow perspective, the device "products design organizations" (Sanchez and Mahoney, 1996: 64) could be a viable strategy for organisational design. In this case it would mean that the delivery of the engine room would be structured and partitioned in sub-scopes as indicate by Figure 4-8. Special consideration has then to be devoted to the integrating teams designing the integrative systems, so in order to overcome the "integration problem" articulated by McCord and Eppinger (1993).

Another interesting observation is that some systems seem to exhibit a kind of 'inverse dependency' in design in comparison to that in the product architecture. Take a look at rows 12 and 21 (systems 1.12 and 2.7) in Figure 4-6. The output-interfaces of the corresponding systems translate to input-dependencies in design which can be seen as interaction points in the corresponding columns 12 and 21 in Figure 4-11. In other words, it seems that whereas systems 1.12 and 2.7 are vital for the functioning of many other systems, the situation is the opposite in design, that is, systems 1.12 and 2.7 are designed according to output from other systems (that are functionally dependent on systems 1.12 and 2.7). In fact, the prime mover (system 1.1) exhibits a similar phenomenon, however, in the opposite direction. This all could be interpreted as a case where 1.12 and 2.7 are integrative systems that are being tailored (or at least adjusted) according to the design of some other systems. In case of the prime mover, one could also draw a parallel to the concepts of core and peripheral systems, which exhibit the dynamic that the latter are adjusted after the former after it has been given a dominant design (Tushman and Murmann, 1998).

Moreover, there seem to be some systems where the design interactions cannot be traced back to an interface in the product architecture. Such cases are e.g. systems 1.2 and 1.14 in project design (Figure 4-10), systems 1.11 and 3.1 in basic and detail design (Figure 4-11) and systems 3.8 and 3.9 in both design phases. These are also interesting and might be examples of what Sosa *et al.* (2004) term a "misalignment of product architecture and organisational structure". Such misalignments are caused by various reasons and are an interesting topic in their own right, which, however, lie beyond the immediate interest of this thesis and will therefore not be further discussed here.

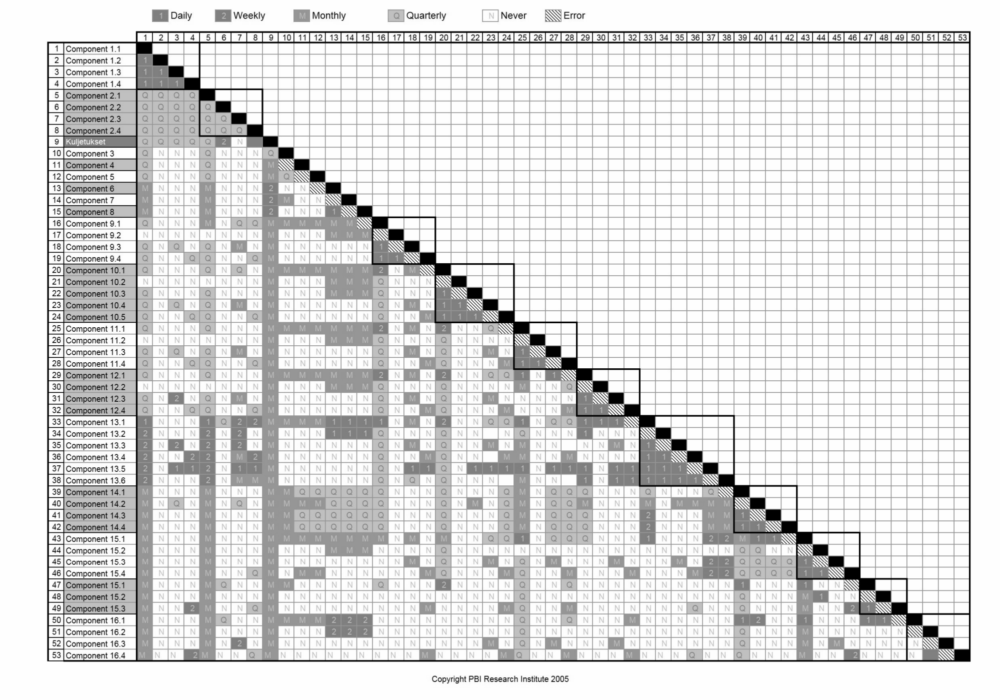
The idea was also to record a DSM for the installation phase using the same breakdown structure. It proved to be too difficult a task, though, as machinery installation follows quite another logic due to the emphasis on pre-outfitting and preassembly, and due to special space requirements. However, for the cabin area we succeeded in recording both a design and an installation/construction DSM (Figure 4-12 and Figure 4-13 respectively). For the design process the same kind of procedure as in the engine room case was used. Consequently Figure 4-12 reflects the interaction of designers and/or design teams in a perceived cabin area project. In this case, representatives from both a cabin manufacturer and an engineering company together filled in the matrix, now using a four point scale (see the legend in figure).



Copyright PBI Research Institute 2005

Figure 4-12 Process-DSM of the cabin area (design)

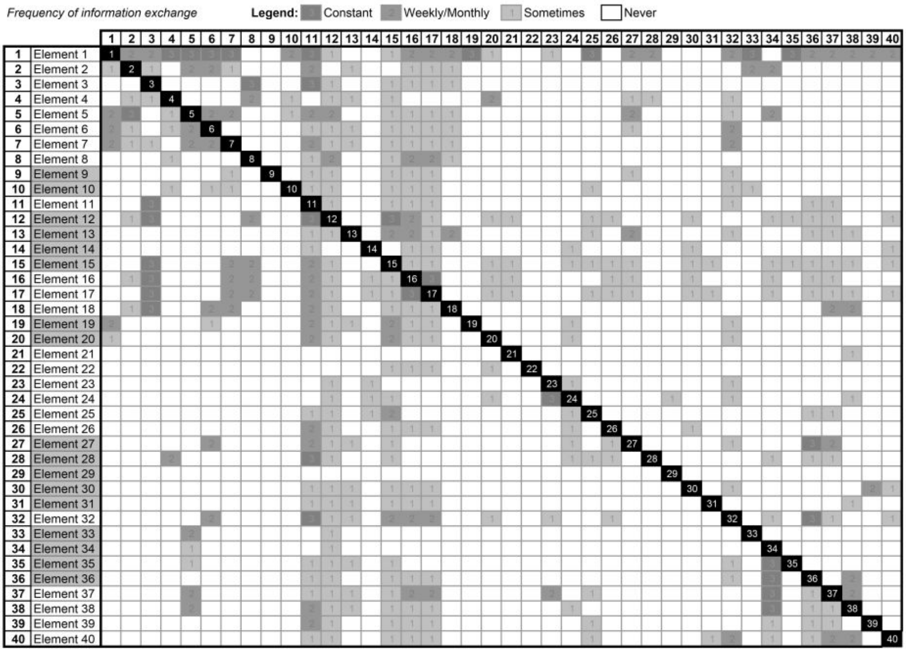
Figure 4-12 we can see that the information structure follows the product architecture shown in Figure 4-9. As already indicated when discussing the product architecture, the process DSM yields a somewhat clearer picture of the dependencies in the product. It is now possible to more precisely identify some more clearly marked wholes on the one hand and some most integrative parts on the other. Still, as we cannot escape the fact that the elements of the product are very integrated, the conclusion from the discussion on the product architecture of the cabin area holds: the product (and the process) architecture is an integral one and should be treated accordingly. Figure 4-13, which shows the corresponding DSM for the installation and construction process further supports this argument. Both Figure 4-12 and Figure 4-13 show some areas, in this case the same, where the interaction is denser. This could indicate the current way of sub-dividing the area is quite good with respect to modularity. On the other, we can see that the design and the installation processes contain lots of different interaction points between the sub-scopes.



Copyright PBI Research Institute 2005

Figure 4-13 Process-DSM of the cabin area (installation/manufacturing)

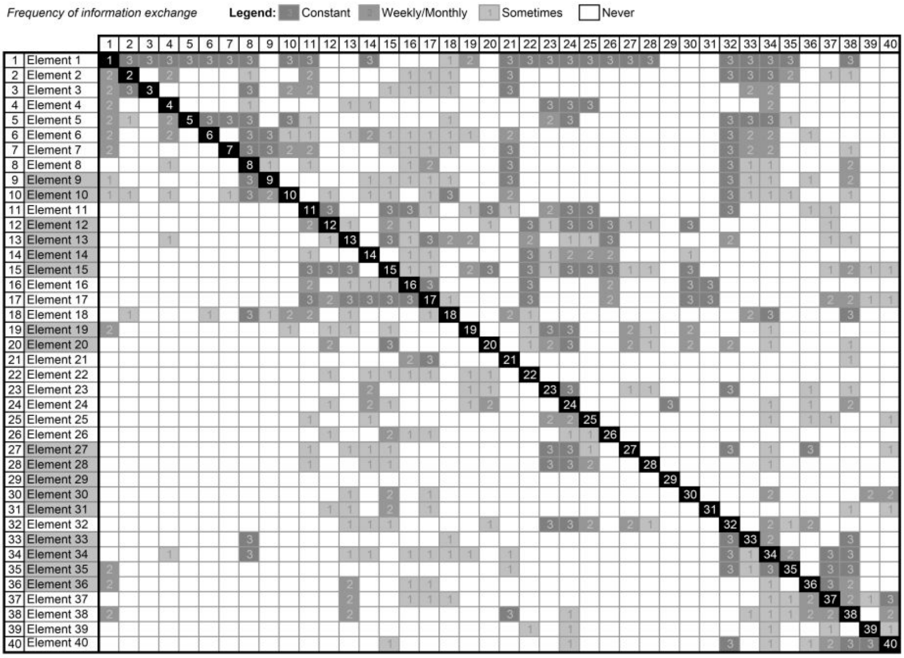
For further comparison, I include a design and installation DSM of the public areas in a ship, such as bars and theatres (Figure 4-14 and Figure 4-15). These DSMs further underline the idea that civil construction traditionally, and in this case in particular hotel function outfitting, is fairly integrated. Two arguments could be outlined on the basis of this insight. First, it is likely to be worthwhile trying to create a more modular product architecture considering the frequent design and installation team interaction the product results in. Second, as this (a modular product architecture) is not to all parts possible, the integral public spaces in question constitute as such a basis for a turnkey scope, which like the cabin area also is the case in this example.



Copyright PBI Research Institute 2005

Figure 4-14 Process-DSM of the theatre area (basic and detail design) (for more information, see Hellström and Westerholm, 2005)

In relation to the second insight in paragraph above, the practitioners often refer to a "modular of working" onboard the ship. This means that (regardless of whether the product can be made more modular) also the installation (or turnkey contract as a whole) need to be carried out in a isolated fashion so in order to reduce the work done on board and the interfaces between different installation teams on the ship (compare with Figure 4-15). Extending Baldwin and Clark's "modularity in"-concepts this could be called 'modularity in installation'.



Copyright PBI Research Institute 2005

Figure 4-15 Process-DSM of the theatre area (installation) (for more information, see Hellström and Westerholm, 2005)

4.1.6 The management process

So, what does this all mean for the project management or the delivery function at large? Indeed, shipyards differ much when it comes to the way in and extent to which modularity is utilised. In this thesis the interest is in modularity when used to leverage new business concepts. Consequently I have chosen to study and describe the project management process of one yard that has taken ‘modularity in organisation and management’ to a further level. This concept builds on a decentralised value creation process which is coordinated by the yard. The yard has kept large parts of basic design and hull assembly in-house, but contracted a considerable amount of suppliers for certain large areas (such as the cabin and public areas mentioned above) on a turnkey, or rather solution providing, basis. This forms the core of their delivery concept, “the assembly yard”.

Although not explicitly making reference to modularity at this area-level of the product, the same kind of requirements for independency is relevant for turnkey scopes. In fact, the turnkey suppliers are coordinated mainly for the interacting points between them (and between them and the yard). This way the yard has been able to significantly reduce the amount of tasks followed up, by the order of magnitude from several thousands to a few hundreds. In addition to full responsibility for respective areas the chosen suppliers are also asked to bi-weekly provide updated time schedules over their installation works. These schedules are integrated with the master schedule, design schedules and the yards own production follow up systems. This way the project management is able to coordinate the by nature very integrated ship systems.

Earlier change works constituted a big cost account for the yard, when suppliers from different fields shared one bigger scope and invoiced for all extra work that were caused by the many intersections and crossing points. As a result of the new way of working the yard has in contrast been able to reduce such change orders to a minimum. The whole set-up resembles the "modular consortia" approach known from the automotive industry (Collins *et al.*, 1997; Marx *et al.*, 1997).

According to representatives of project scheduling and control of the concerned yard, one of biggest challenges with the "assembly yard" idea has been to teach the new first tier suppliers to handle their projects (cf. Brady and Davies, 2004). Now the detailed planning and scheduling earlier done by the yard has to be done by these suppliers. As a result of one of our DSM-based research projects, one major supplier to the yard also realised that it now has to look over its own supplier base and the way it handles that interface in order to avoid unpleasant surprises.

Given the good experiences with the turnkey-contracting, other yards in Finland have started to take action to adopt the same kind of business concept. One could say that they use modularity as a means for coordinating the network of internal units, suppliers and partners; as a systems integration mechanism. The use of modules (structural) is promoted by actively seeking new objects for modularisation: in some cases by leaning and encouraging suppliers to develop and suggest 'new ways of doing old things', in other cases by integrating formerly separate (technical) functions into a larger whole (which might require cooperation among suppliers within the network) *etc.*. For the turnkey contractors, the importance of a 'modular way of working' is stressed (see the previous section).

4.2 The energy systems case

4.2.1 Industry characteristics

There are significant changes going on in the energy business due to a number of factors including the liberalization of energy markets, the increased focus on environmental issues and the development and commercialisation of new technologies. As a result the optimal plant size is in the future expected to lie within the size range typical to distributed energy systems as depicted in Figure 4-16 below.

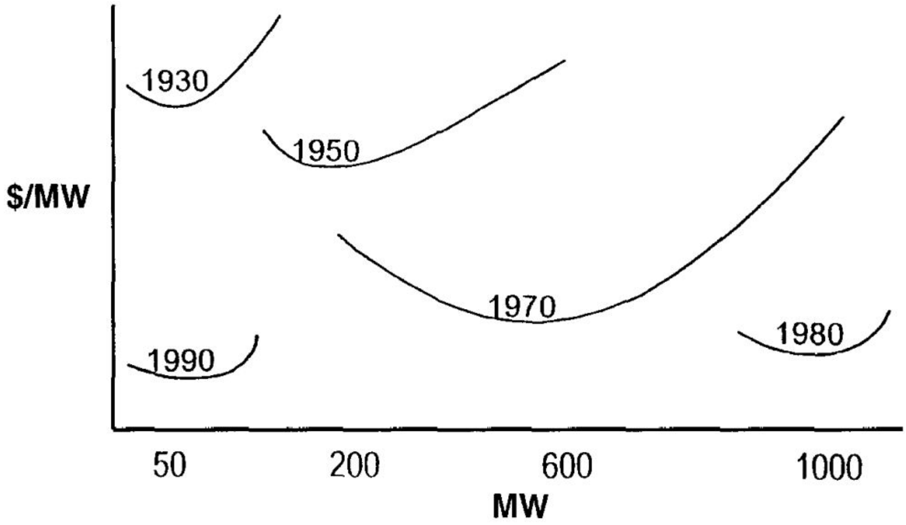


Figure 4-16 The change of the optimal plant size in power business (Linden, 1997: 16)

The delivery of distributed energy systems is bound to differ from that of centralized large-scale systems. For instance, in moving towards smaller generating units (see e.g. Linden, 1997; IEA, 2002) economies of scale in equipment manufacturing are likely to be realized at least to some extent. Hence a different type of management skills are needed (Magnusson, Tell and Watson, 2005). Moreover, new players are emerging, whereas the roles of the existing might be changing etc (Budhraja, 1999). New kinds of services might be needed and so on. When talking about decentralised and/or distributed energy production the thoughts are typically directed towards ‘new’ technologies such as especially fuel cells. However, a set of existing technologies constitute a major part of at least the short-term potential for realising distributed energy production. For such companies the distributed energy market rather poses a challenge in finding new business models for operating with smaller absolute margins. As one manager in one of the case companies expressed it:

> We’ve got the elephant disease. A 100 MW power plant in the middle of jungle anywhere in the world, no problem, we can do it. But for a 10 MW station one extra trip for the site engineer and we’ve lost our margin.[1]

Moreover, since the mid-1970s the strategies in electricity business have been changed to explore and exploit the opportunities stemming from the liberalisation of electrical markets around the world. As a consequence, electrical systems suppliers pursuing a systems integration strategy have had to transform into “loosely coupled” organisations that can easily join to meet the demand for projects with various constellations. (Tell, 2003). This still constitutes a challenge that suppliers of electrical systems still have to cope with.

The technologies considered in this thesis are diesel and natural gas fuelled reciprocating engine and bio-fuelled boiler plants. The former was used for energy production already in the 19th century, but the steam turbine soon became dominating way of generating electricity. However, since the 1970s the reciprocating engine has again regained market share especially in projects in more remote parts of the world. Although the product concept is based on an old invention it still continues to develop, much driven by a demand for higher operating efficiency and environmental regulations. Consequently, especially gas and combined heat and power (CHP) solutions have become more requested and constituted a technological challenge for the suppliers. One of the newest technological challenges is indeed the increased demand for air conditioning. To meet this demand suppliers have had to rapidly develop so called combined chill, heat and power-solutions (CCHP), that is, power station capable of producing both chill, heat and electricity.

4.2.2 Product and process characteristics

Reciprocating engine- and boiler-based power plants are typical systemic capital goods. Both consist of several sub-systems such as building structures, fuel systems, cooling water systems, steam systems, voltage systems of different levels (low, medium and high) and control systems. Hence they include a certain degree of complexity and a wide array competencies must be mastered to be able to deliver

---

[1] My free translation from Finnish.

such plants. In addition, both types of plants can be used for combined heat and power (CHP) production, which makes them a part of two quite different meta-level systems: the power grid and the district heat loop.

The power plant delivery process entails elements from two major types of projects: product development and construction. Although the parts of the plants are considered fairly standardised, each project typically requires a considerable amount of engineering. The delivery process for the engine case will now be described. The outcome from the sales phase, the preliminary design, can in principle be configured from a set of standard technical processes, as described by Meklin *et al.* (1999). The embodiment of the processes into structures and components is however left to be decided in the basic design. Finally, the detail design is made either by an engineering company or the supplier of the component in question. In reality, however, the engineering is not necessarily such a straightforward process and depends much on the type of the project and a variety of other reasons (Lindholm, 2004). It is also good to remember that the distinct feature of plant delivery projects is the fact that the building site is never exactly the same. Indeed, as one experienced civil engineer at the case company expressed it:

> *There are no standard plots, there are no standard soils, there is no standard nature, and remember that there are not any standard houses, only standard concepts it* (Lindholm, 2004: 43)[1].

In the case company the design (as well as the construction) is executed discipline wise: mechanical, electrical and civil. The logic of the design follows a path that starts with choosing mechanical equipment to fulfil the promised power output. Then electrical equipment and circuits are designed, on the one hand, to meet the electricity consumption of the generating equipment (low voltage) and, on the other, to transform and transmit the generated power to the grid (medium and high voltage). Finally civil structures are designed to shield and support the mechanical and electrical equipment. (Lindholm, 2004).

Once the design has proceeded far enough for the respective equipment to be specified, that material can be procured. When procured and manufactured the material that is not locally bought is collected for the shipments. Besides these transportation is big issue in decentralised power plant deliveries given the remote locations of the plants and the weight and size of the material that need to be moved. This asserts special requirements on the material and the management process.

---

[1] My translation from Swedish.

In the building process, in turn, the field-specific activities are basically executed in an almost reversed order compared to the design process: first, of course, the civil structures have to be put in place where after the mechanical equipment can be installed. Finally, the electrical equipment is installed. The building process then ends with an intensive commissioning phase.

Although presented sequentially here, in practice the activities overlap to a large extent. Upon delivery typically a 1-2 year warranty is given for the plant and the equipment by the delivering company. As a whole the plants may be operated for some 20-30 years. Besides the operation activities, a large amount of services in the form of maintenance works are more or less continuously needed at the plant. Given the long period of operation and maintenance even small issues in the product structure might become costly in the end. Thus this part of the life cycle is most important to bear in mind when designing the plant.

In sum, Figure 4-17 shows what we call a ‘product-service tray’, where the power systems breakdown has been combined with a process breakdown of a typical power project. This tray or palette is below used for the analysis of the product-process structure of power plant deliveries.

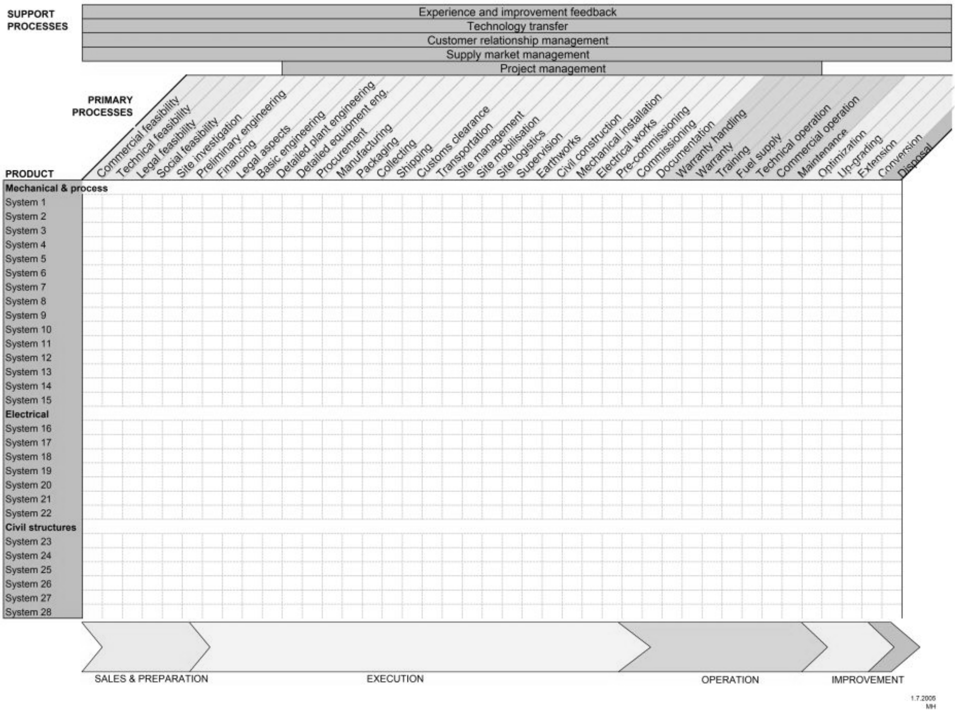


Figure 4-17 A power plant delivery perceived from an integrated product and process breakdown

4.2.3 Product-process diagnosis

Generally speaking, the current power plant (or energy systems) product concept of our case company in the reciprocating engine business is a result of some two decades of development work. The concept is based on a modular plant design and standard parts and thereby enables fast and flexible delivery. One of the biggest benefits with the concepts is undoubtedly the pre-fabricated, preassembled and partly pre-tested modules that shortened delivery time. Especially the amount of piping work on the construction site has been significantly reduced through modularisation and prefabrication. Most modules also remain unchanged from project to project (or changed merely by way of parametric modelling), thus implying considerable savings also in design, given that the annual volume of projects is counted in several tens (up to 50). Still the word “module” seems to mainly be used in the “building block” meaning and several different denotations are used more or less interchangeably:

modularisation, prefabrication, unit, skid, preassembly etc. A good example of such a module as described above is the "factory built unit for fuel conditioning" described by Storholm and Wikström (1995: 13). To underline their argument they show two pictures of the unit: one with all the unassembled components needed for the function in question and one ready assembled. The case company has continuously been looking for similar opportunities to create pre-manufacturable objects. To date one could probably say that most of the potential is realized (although not all); at the building block level, that is.

The industry evolution has taken the case company to a position where it is a major player along the value chain on a fluctuating market partly bearing the risks of both its customers and its suppliers. A current development trend is therefore the move towards larger scopes of sub-supply and to adopt a kind of utility and life cycle thinking of the hardware like in many other industries. By dividing the scope in to more manageable parts the hope is to share the systems integration risks with certain first tier suppliers that are ready to assume a greater responsibility around their product. One could even argue that this way the risks are allocated to the level where they best can be managed.

If big systemic products are to be profitable in the distributed energy systems market the both the product and the way of working have to be streamlined. To explore the issues of both distributed energy systems and the move towards larger, modularised scopes the energy case company consortia was asked for their opinion (project E-2 in Table 3-a). Figure 4-18 shows the different opinions and ideas as distributed over the delivery chain.

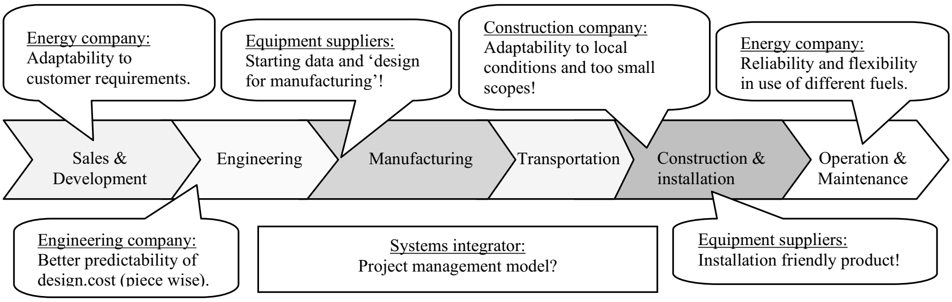


Figure 4-18 The distribution of the arguments of different players in the value chain/stream (for more information, see Hellström *et al.*, 2005)

Among others the typical gap between design and manufacturing was addressed, as can be seen in the following quote of a director of an equipment manufacturer:

> *Maybe one should look more into what kinds of raw material are available in the warehouse, which is real-life for us all the time, but not for the engineering company, who does these jobs. That is, the approach to design is different [...] there they invent the measures and then one tries to find out some way to get it done. It is like where you happen drop the line on your [CAD-screen].*

The same kind of issue was raised by the other equipment supplier, who told us about how the construction industry continuously rejected his installation-ready equipment (see Figure 4-18 above) due to its higher price, although it would be apparent that such an innovation paid off in reduced installation and life-time costs. The construction company representative, however, admitted that this is a problem, but reminded us that one never can be sure of the reduced life-time costs, and that this very seldom is warranted but rather a mere promise. Sadly enough, this seems to be the destiny for many innovations in project business. Due to the lack of trust in temporary relationships and due to the technological risks in novel solutions companies avoid using them in their projects and after the project when the temporary networks are dissolved the innovation is forgotten.

Given the extensive amount of different phases and processes the product has to pass through there are bound to be several other gaps like the ones described above. In fact, the product (or module) might even be perceived very differently from phase to phase: for some the performance matters, for others the size, weight or documentation and so forth (Gustafsson *et al.*, 1999; Lindahl, 2001). On the whole, this could be interpreted as a need for introducing larger scopes of supply also process-wise, which as we have seen in section 2.4.2 is not a clear-cut issue (von Hippel, 1990). The current practice in the case companies of dividing a project into sub-scopes is, however, is far from what often referred to as "systems sourcing" (see e.g. Gadde and Jellbo, 2002). Figure 4-19 shows a filled in product-service tray (Figure 4-17). The different colours resemble different suppliers. The data has been gathered from real projects at the case company (project E-2 in Table 3-a). Note that the product breakdown is done at a rather high level, at a combined sub-systems/systems level. If we refined the breakdown to a lower, say the building block, level we would receive an even more motley tray. It should also be noted, as was pointed out by one manager in the case consortia, that such process integration does not necessarily mean larger scopes of supply in terms of service provision, but also represent an attempt to embed some of the services in the product such as the provision of pre-tested, ready-to-install and easy-to-maintain products (or modules).

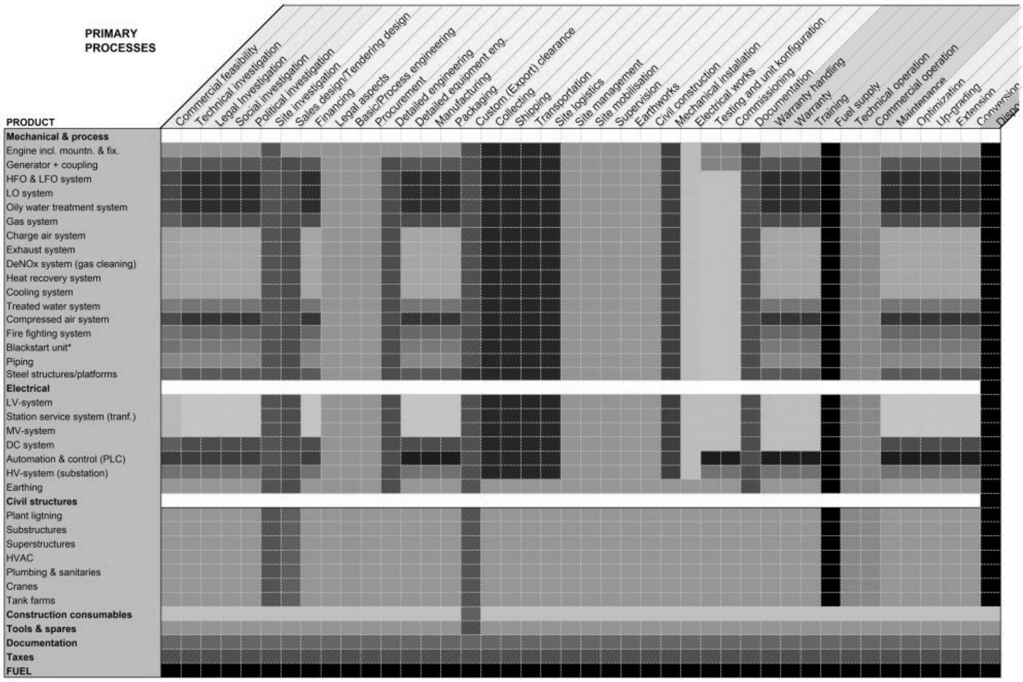


Figure 4-19 The scope division seen in a product and process breakdown (for more information, see Hellström *et al.*, 2005)

The typical way of organising a palette like this is to think process wise in terms of functional organisational units like design (conceptual, basic and detailed), purchase, manufacturing/production, field work, warranty, operation and maintenance etc. The product is then acquired on a component or material group (pipes, cables) basis, especially when it comes to mechanical equipment, whereas equipment used for electrical systems tends to be procured in slightly larger scopes (Lindholm, 2004). This way of organising (or partitioning using von Hippel's vocabulary) has at least two disadvantages brought up in the case study. First, as contended above, several other gaps like the design-manufacturing interface mentioned above emerge and might constitute a communication barrier. Consequently, the true requirements for each phase or set of tasks are not always known or taken into account in preceding phases. This then of course requires major integration and concurrent engineering efforts which are not always easy to handle. Second, all the product and organisational interfaces are to be handled by the project management. From this it is easy to see that such "component integration" and task coordination requires a considerable work effort and becomes the pre-occupation of project management. At the same time the system integrator company in our consortia would like to streamline its project management model and make it more agile. Up to now this company takes on most of the risks in the deliveries itself. One could further argue that some of the time freed from the component level interfaces should be invested in managing the customer and other relationships in the deliveries, because, as another manager at the company explained, "that is where most of our failures come from in the end".

One concern within the case company is the risk of industrial plagiarism, because a standardised and modularised building block is much easier to copy than a standardised, but modular and 'decentralised' concept. The latter gives the company a competitive edge in the way it connects the 'modules', that is, in essence, a superior way of working (configuring, assembling, operating etc). A fully pre-defined and preassembled module does not entail the same advantage. However, such an edge has to be balanced against the extra costs incurred by not embedding all such 'services' in the module.

The customer need is of course a strong determinant when talking about modularity. Basically, we should ask ourselves what kind of variability the customers want. It seems, when asking some project managers at the systems integrator company, that typical changes to the standard concept include changes to the layout of the plant and the pre-condition to use some equipment of a certain manufacturer. Another source of variability is the amount of auxiliary system units which depends on the desired operating profile and degree of the reliability of the plant. The same kinds of issues often form the source of customer-initiated change orders, which are common in this kind of business. In another study by PBI, concerning the customer satisfaction of bio-fuelled boiler-based power plants (project E-3 in Table 3-a), it was found that the customer actually did not want as much customisation as the supplier thought was necessary (Gustafsson *et al.*, 2003). In fact, for some equipment it was quite the opposite due to the concern for part availability and delivery time. One could summarize that the demand for customisation was mainly concerned with the heterogeneity of the incoming fuel and thereby the fuel treatment system, and restrictions on emissions. The latter is of course dependent on local legislation, which in turn can be seen as a part of the bigger issue of local adaptability. Local adaptability includes physical issues such as ambient conditions and grid parameters, but also social issues such as legislation, availability of and competence of the operating staff etc.

4.2.4 Product structure analysis

The next step then, like in the ship case, is to take some action in analysing and restructuring the product. Although the above diagnosis has mainly been done in a case around the reciprocating engine, the same issues are likely to be encountered in one way or another regardless of technology in any energy systems industry, not to say any manufacturing industry. As the reciprocating engine based power concept is fairly established and modular as it is, we have chosen to investigate another, more integrated technology, namely a bio-fuelled boiler plant (project E-4 in Table 3-a). Figure 4-20 shows the building block level product DSM for such a plant. The product decomposition is based on the company's own WBS. In order to incorporate all four types of dependencies (spatial/structural, energy, material, electricity/automation signal) in a two-dimensional view, the following 'scoring' system was established: (10 = energy or material, 11 = spatial/structural, 15 = electricity/ automation signal). Hence we know from the first figure how many of the different interaction types and from the second which interaction types are present at one interface. Simply put, the higher the 'score' the 'stronger' the interaction and the darker the grey colour indicating the 'strength' of the dependence between two elements of the product. This procedure was established rather for a visualising purpose than for engineering-based strict decision support. (for more information, see Gustafsson *et al.*, 2005).

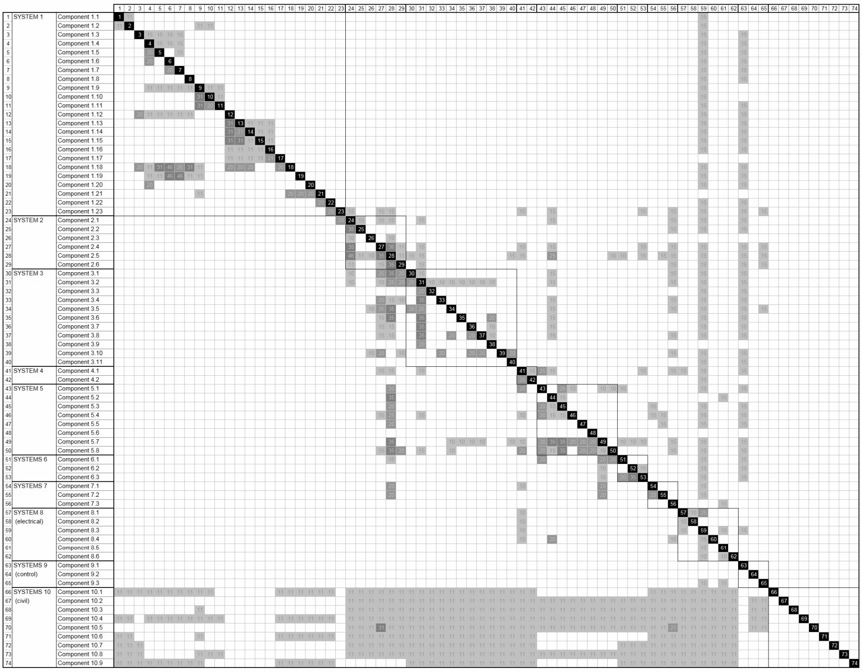


Figure 4-20 Product-DSM of a boiler-based power plant (for more information, see Gustafsson *et al.*, 2005)

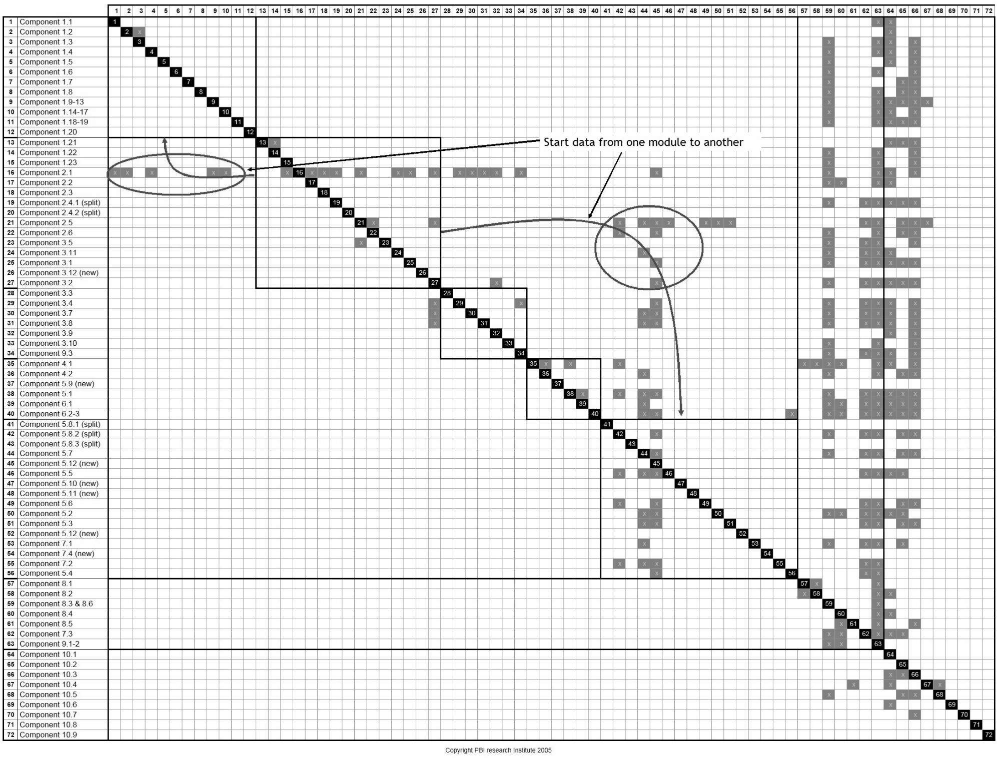
The DSM with some suggested element-clusters was shown at a workshop with managers and engineers from different organisational functions of the product company. The suggested clustering was 'falsified' (see section 1.4.4 and 3.2) and possible rearrangements were suggested by the workshop participants. All kinds of arguments were put forward, many of which were even contradictory. For example, for one system it was clearly shown that a major part of the warranty costs was due to the fact that the product company lack the capabilities to handle the technology in question. During the process of setting up new system structure also installation and maintenance aspects were considered. The outcome of the rearrangement process is shown in Figure 4-21.

Figure 4-21 Re-structured product-DSM for the boiler plant (for more information, see Gustafsson *et al.*, 2005)

Although the new structure still entails some unsolved problems, it provided what one could call 'the reasonable compromise' given the objectives of the restructuring (cf. Toulmin, 2001).

4.2.5 Process structure analysis

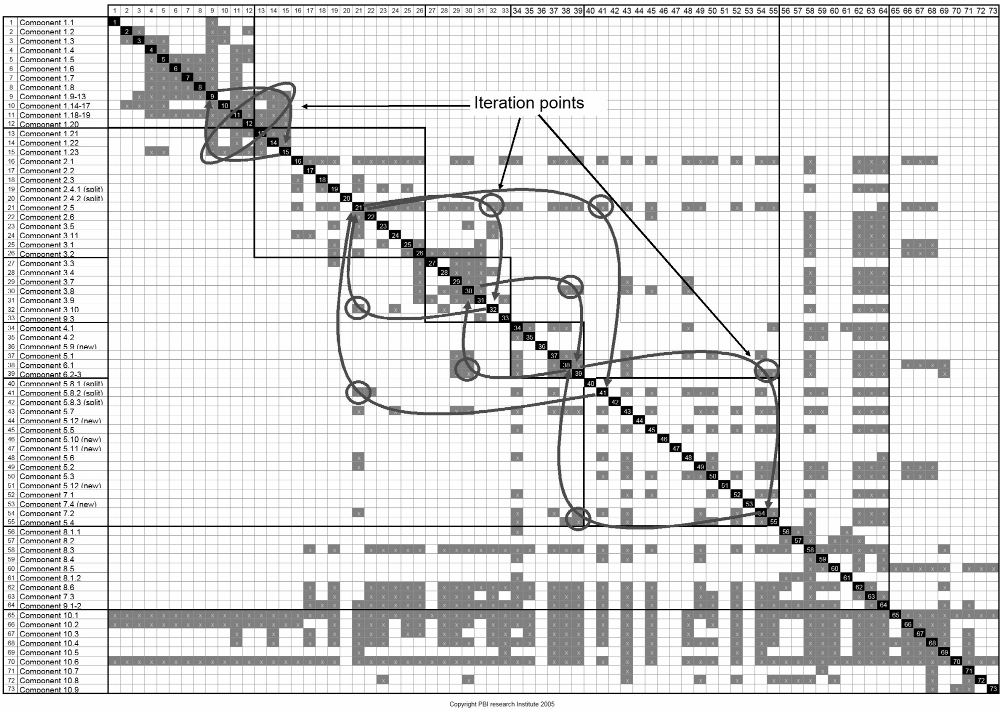
We now turn our attention to the process interactions and analyse the information structure based on the system clusters established in the product structure analysis. Figure 4-22 simply shows the design inputs (and outputs) from one task or component to another.



Copyright PBI research Institute 2005

Figure 4-22 A DSM showing the information structure of the design activities in a power plant project (for more information, see Gustafsson *et al.*, 2005)

First of all, we can see that the information structure of the design phase follows the product structure in Figure 4-21 above quite well, although there are considerably less interfaces in the design structure. This may be a result of a high usage of standard components and standard part solutions that once set do not require re-design. As expected, however, the integrative systems translate into a need for integration in design. We can also identify the same kind of 'reverse dependencies' seen in the ship case. The reasons for these are thought to be the same as or similar to those discussed in section 4.1.5. As for the civil structures we can clearly see the reverse character of the dependency mentioned above in section 4.2.2 when discussing the design sequence of the systems and disciplines of a power plant. That is, the civil structures carry and support the rest of the plant equipment and are thus typically designed according to the dimensions (especially weight) of that equipment (receiving a lot of input data in the design phase as seen in Figure 4-21). In the installation phase the situation is quite the opposite, however. The civil structures of course have to be among the first equipment in place and hence provide a lot of input data (e.g. schedule information) to the installation of other equipment as shown in Figure 4-23.



Copyright PBI research Institute 2005

Figure 4-23 A DSM showing the information structure of the installation activities in a power plant project (for more information, see Gustafsson *et al.*, 2005)

In general, Figure 4-23 provides a messier picture of the project. Among other things, we can identify several iteration loops that Eppinger (2001) writes about. The existence of such loops can be especially damaging in installation and construction as it might result in a need to tear down some already installed structures. Furthermore, such loops make scheduling more difficult. The messiness can be taken to imply that the product based on Figure 4-23 can be considered fairly standard, whereas the process structure (in this case in installation) is not yet well established and routine. Meklin *et al.* (1999) made a similar conclusion in there investigation of product and management processes in Finnish project companies. In our case, the messiness probably also reflects the ongoing changes in the product structure.

4.2.6 The management process

The manager of the delivery department was initially chocked and surprised when we showed him Figure 4-19. He had obvious difficulties with accepting the amount of both product and different organisational interfaces that his project managers had to handle. According to his vision the role of his department should be project coordination, not 'micro-management'. Given all these interfaces it is easy to realize that the huge effort they require directly reduces the time that can be devoted to other activities such as relationship handling. Another manager at the delivery department maintained that it is in the relationships most of their projects fail if they do. In the search for a project management model that would take into account these issues our contemporary research project in the marine industry provided an opening. We then constructed a model based on the idea of modular systems and solution providing. This did not immediately make perfect sense among the energy systems representatives. However, after combining our experience from ship building with the DSM-analyses we were able to provide more verbal and illustrative arguments for what could be seen as a new delivery concept for decentralised energy systems, which was received much more positively.

The proposed delivery concept was constructed for (and during) a follow-up workshop to the DSM study of the bio-fuelled boiler plant (project E-4 in Table 3-a). The workshop was held in order to incorporate modular way of working in a real project that was coming up. The concept takes its departure from the product architecture, more specifically from the modular (and integrative) systems identified (see section 4.2.4, notably Figure 4-21). The modular systems then constitute the basis for what could be called 'sub-projects', which constitute a kind of full solutions offering design, installation *etc* to be provided by each supplier of the modular sub-system. From a project management point of view the delivery is then managed merely by the dependencies or intersecting points between these scopes, as in the ship case. They thus constitute coordination points or a kind of milestones, if one like. It is to be noted that the dependencies are different from phase to phase; compare the information structure of the design phase in Figure 4-22 with that of the installation phase in Figure 4-23. Basically every information dependency that is located outside a modular system boundary constitutes a coordination point according to this logic. Focusing on the modular system and its dependencies throughout the project (and not merely as usual, on the phase throughout the systems)[1], we obtain what could be called a 'functional module' (compare with the idea of "integrated solutions" in

---

[1] To draw a parallel to football (or basket ball): a player is typically advised to keep his eyes on the ball and not the distracting moves of the player with the ball.

section 2.10.2). The idea is depicted below as a traditional network diagram (Figure 4-24).

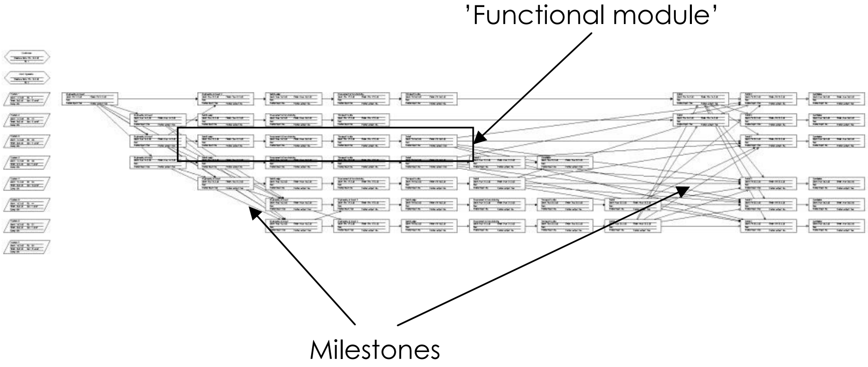


Figure 4-24 The delivery seen as a network diagram (for more information, see Gustafsson *et al.*, 2005; Hellström *et al.*, 2005)

When the sub-projects in addition to the structural (or rather informational) dimension are given durations (i.e. a time dimension) we see further interesting things. One of the benefits with the 'functional modules' is that the modular sub-projects can be executed in parallel (cf. Sanchez and Mahoney, 1996), which is more than letting phases overlap as in concurrent engineering. This is depicted as a conventional GANTT-chart in Figure 4-25.

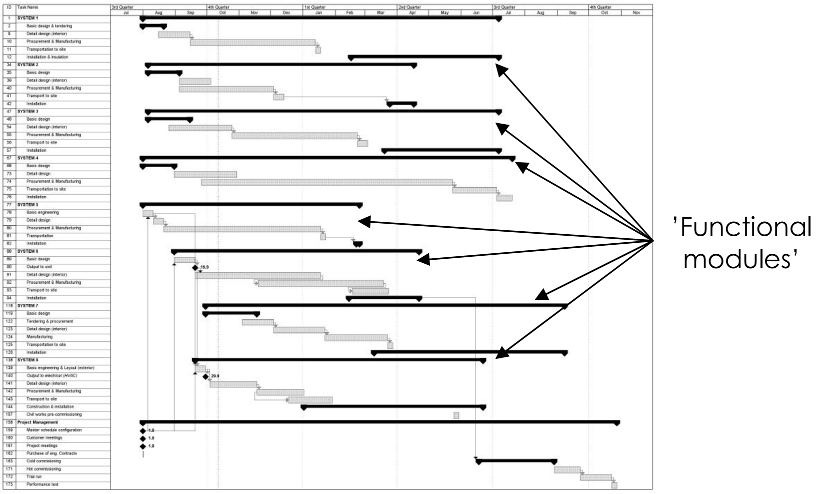


Figure 4-25 The delivery seen as a GANTT-chart (for more information, see Gustafsson et al., 2005; Hellström et al., 2005)

We can now think of the constellation as a fictive game, where the sub-project managers play against each other in not being on the critical path. To give a simple example with only two players, A and B: If A is dependent on B:s input, then B should strive to generate is as soon as A needs it. As soon as B succeeds in doing so he is not on the critical path anymore, unless A, in turn, manage to speed up his sub-project so that he can make use of B:s input at an earlier point in time, an so on. One way to speed up one's sub-project is to partition it into further sub-tasks. However, this should only be done if the partitioning can give us a chance to generate a specific output earlier. Otherwise it merely provides us with an 'unnecessary' level of detail.

5 DISCUSSION

In this chapter the phenomenon of modularity is discussed by comparing, contrasting and synthesising the findings from the two cases with each other and with extant literature in order to reach a comprehensive answer to my two research questions. The findings can be considered a framework that describes a perceptive "business concept based on modularity" that could be pursued by companies delivering large, systemic capital goods.

5.1 Two complementary cases

To begin with, it shall again be pointed out that my use of two case studies does not imply that my primarily aim would be generalisations to the broader, perceived analytic category of project business. Both industries studied in this thesis show their own characteristics and industry logics that reflect the past and ongoing changes in their operating environment in combination with the very nature of the industrial activity in question. One quite fundamental difference between the two cases (or between project businesses in general) can be seen from Figure 5-1. The production efficiency typically characteristic for be shipyards can be derived from the stationary building site. In contrast, decentralised power projects are often located in very remote (not to say exotic) areas where the availability of skilled manpower, electricity and clean water are not always obvious. A shipyard can thus also benefit from using the same network for different activities in a project, whereas a power system supplier may have to use new sub-contractors from project to project. On the other hand, the aim with decentralised power plants is provide nothing else than electricity, at times even to places where no real competition on the electricity market exists. Luxury cruise ships, in turn, are often built with the aim to be the biggest and most exclusive in its class; to give passengers extraordinary experiences that they never have had before.

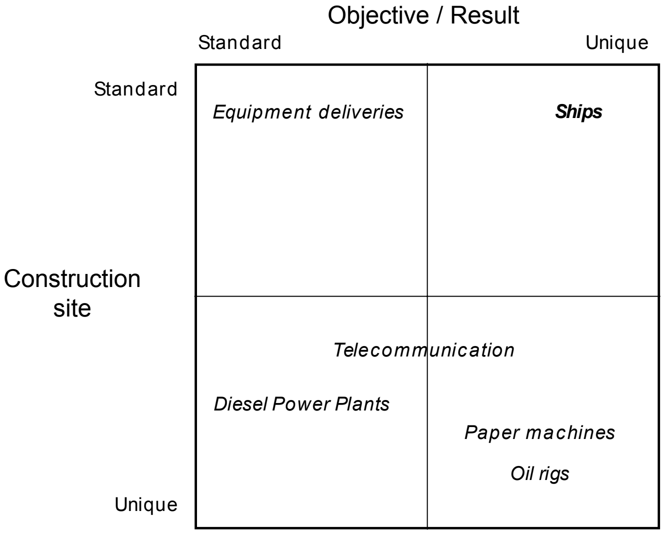


Figure 5-1 Categorisation of projects according to type of site and objective (Wikström, 2000: 15)

It is also quite obvious that the level of technical complexity is much higher in ship building as it includes more systems to be integrated. In a way one could say that the power plant corresponds to just one major system in the ship, i.e. the engine room. In other words, a ship is situated at a higher hierarchical level than a power plant and could be perceived as a kind of 'meta system'. The corresponding 'meta system' in the energy systems case would then be for instance the local community (where it would be a part of the infrastructure) or the power network where the power plant is placed (where is would be only one node). This is, however, merely a matter of perception and could easily be looked at in yet another way. And on the other hand, in terms of social complexity decentralised energy system deliveries might equal, if not supersede, ship building given the long and complex delivery chain and the often remote construction sites of the former. Moreover, the industry programmes that this thesis is based on have been addressing slightly different issues (see Table 3-a and Appendix 1), which further makes direct comparison difficult.

Despite all this, it is possible to identify some kind of common phenomena and patterns. Above all, what makes the two cases comparable for this study (in addition to the very fact that both are concerned with CoPS or CoPS-like[1] artefacts) is the fact

---

[1] For a general discussion on the nature of CoPS-products perceived as an analytical category, see Hobday (1998: 690-692).

that in both cases the product levels, the ship and the power plant, constitute the object of the transaction between the main contractor and the owner of these big, systemic capital goods. Furthermore, although the research programmes in the respective industry have addressed slightly different issues, they have one major issue in common: the search for a new business concept based on more networked deliveries and decentralised value creation.

As for the different hierarchical levels of these artefacts, in the ship case the focus has as a consequence of decentralisation also been on the interfaces between areas and overall systems and corresponding suppliers, which are more like the level of the power plant. In this sense, the two cases can be considered comparable. Moreover, also at this level both products exhibit a somewhat 'fractal' nature, i.e. they can be further decomposed at lower hierarchical levels (although not in exactly similar mini-pieces, but in a similar manner).

However, the main point of studying two different cases is to arrive at a more complete picture regarding the use of modularity and modularisation in project business, since different cases might show very different aspects of the same phenomenon. In fact, given the action/clinical research orientation, one idea has been to utilize the learning and the generated knowledge across the cases. Broadly speaking, "modularity in design" and "modularity in production" (using the vocabulary of Baldwin and Clark, 2000) used as a driver for standardisation can be seen as a best practice in the energy systems case, whereas the well developed production system in the ship case has provided particular insight in the issues of project management and "modularity in organisation". These are of course partly direct effects of differences in the product volumes in the first case and the stationary construction site in the other (see Figure 5-1), but can still direct our attention to ways in which the idea of modularity has been successfully utilized.

5.2 What is a 'good module'

My literature review (see chapter 2) implied that the characteristics of a 'good module' can be divided into three categories: first, independence or in other words the boundaries to other modules ("modularity in design or product architecture"), which already lies in the definition of modularity (and from which most other benefits of modularity can be derived); second, the extent to which the same module can be used in other projects, that is, the issue of utilizing similarities between projects ("modularity in use (and production)"); third, the life-cycle aspect, that is, how well the module behaves throughout the delivery chain ("modularity in production or assembly/installation"). The last aspect has also been heavily emphasised in research project S-2 (see Table 3-a). Below I will discuss the two cases through the lenses of these three aspects.

5.2.1 Managing uniqueness – the 'structural paradigm'

Addressing the first research question "what is a good module" I take the current way of using the concept as a proxy for a 'good module'. Clearly, following Wittgenstein (1953), the meaning of a word lies in its use[1]. In this vein, one can argue that the word "module" have received a structural meaning. As such, this has proved to be successful both in energy systems deliveries and ship building through the widespread industry practice of prefabrication, -assembly and -testing. The benefit of this approach lies particularly in moving work from difficult conditions and the situation rich construction site/shipyard to a workshop. This is clearly shows a sort of "modularity in production" (Baldwin and Clark, 1997). In the energy case one has also been able to utilize similarities between projects and pursue standardisation by the same means. In ship building this happens to a lesser extent due to the very nature of the demand.

Generally speaking, the issue of balancing customisation and standardisation lies at the core of industrial capital goods markets as well, although they show different industrial dynamics when it comes to the mass customisation paradigm. For such products the dominant logic has all the time been based on tailor-made solutions (see e.g. Hellström, Westerholm and Wikström, 2003; Sievänen, 2004). However, today's never ceasing pressures to cut costs and lead times have led the creators of unique solutions to more actively seek for standard designs and production. Thus it is merely a question of approaching the same ideal from opposite sides, as illustrated in Figure 5-2.

---

[1] This is an interpretation and a notion my colleague Magnus Gustafsson keeps reminding us all the time.

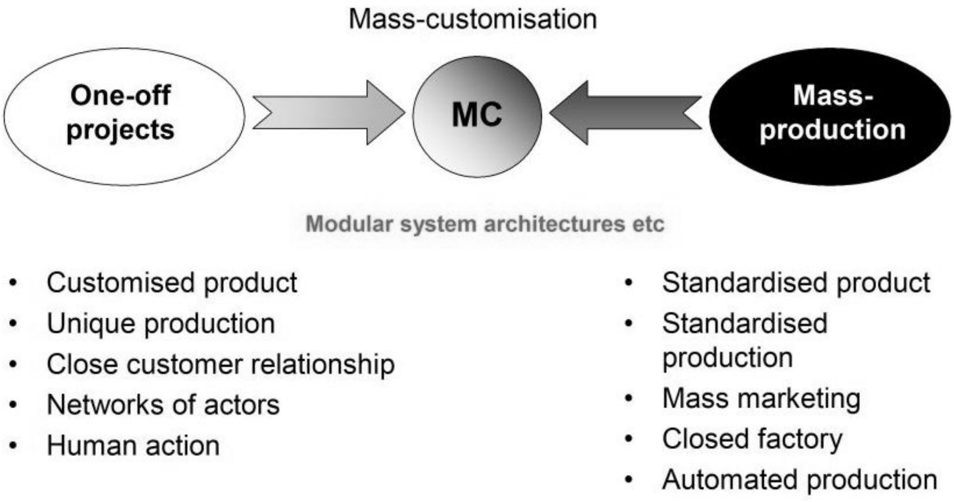


Figure 5-2 From opposite sides

From whichever side this compromise is approached, it is likely to be based on modularity. However, in project business the concept of a module (or the concept of a product in general) becomes different. Rather than talking about product variants in a product family (Meyer and Utterback, 1993; Uzumeri and Sanderson, 1995) that share some modules from a common platform, one could say that in project business every product, or rather the outcome of every project, is a unique variant, but built upon a product concept (that resembles the platform in high volume markets), such as the class concept in the cruise business and power plant type, which among others depends on fuel (heavy fuel oil, diesel, natural gas etc) and intended use (base load, peak load, stand by, CHP etc), in energy systems business (cf. Zhang, 2004).

The outcomes of big, systemic capital goods projects are still likely to remain unique. However, using structural modules (preassemblies) companies can make considerable savings in lead time and construction work, not to mention improvements in quality, and in addition, when repeated from project to project, some level of economies of scale are likely to be realised. For the project business context this basic idea is illustrated in Figure 5-3 (compare with Pahl and Beitz function/module typology in Figure 2-1).

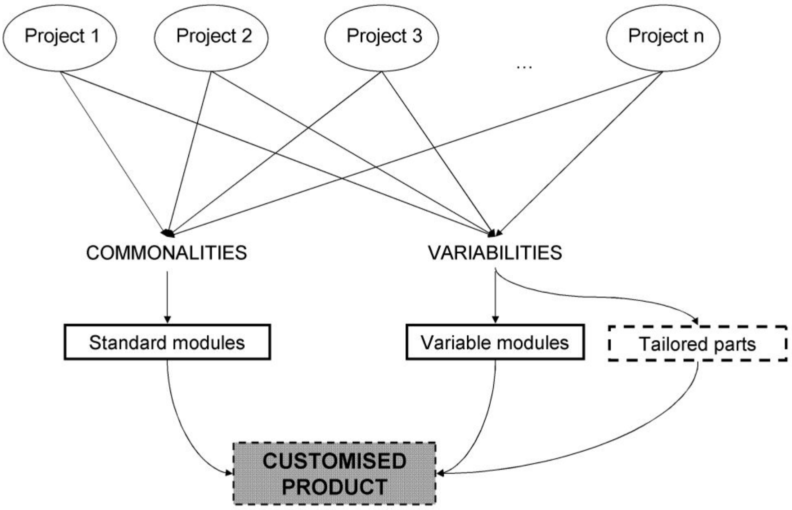


Figure 5-3 Modularity as a basis for customisation in project business

The word "standard" in Figure 5-3 shall not necessarily be understood as the noun for "something established by authority", but as the adjective signifying something "regularly and widely used, available, or supplied" (Merriam Webster Online, 2005). Apparently the extent to which exact similarities between projects can be embodied in a structure and reused is dependent on the hierarchical product level (in addition to the batch size, of course), that is, the level of modularisation (Hsuan, 1999). Indeed, no two cruise ships are exactly the same, but several cabins in already one ship can be duplicates, not to mention the toilets in the cabins or, further, the taps in the toilets. Similarly, in the energy systems case where hardly no two power plant configurations are exactly the same, typically the prime mover (be it a reciprocating engine or a grate-boiler-turbine combination) can be chosen from a few variants/configurations that are produced in series (in batch sizes that are closer to that off mass production). The prime mover is of course located at a rather high hierarchical level of the power plant, but the further down in the hierarchy one goes, typically the more standard the components are (compare with Artto *et al.*, 1998): frequency converters, pumps, fans, wall elements etc. The use of completely standard modules has proved to be difficult still at the building block level. The required changes between the variants are, however, typically rather small and 'configurational'. On the higher levels of the product structure, such as the system level, it therefore makes more sense to talk about "economies of recombination" (Grabher, 2004) than economies of scale.

At the lowest hierarchical level we are bound to find among others bolts and nuts. A colleague of mine, Magnus Gustafsson, often points out that these constitute ultimate modules in the sense that their interfaces are international standards, in size and thread direction; in other words, institutionalised properties that nobody readily questions anymore. However, although one could even argue for the function containment in bolts and nuts, it would today make little sense in building a power plant from such components on site. Instead, it makes sense to preassemble lower level components to a larger unit, so in order to reduce installation work on site (or on board). How far up the hierarchy this way of working can be taken usually depends on the type of (sub-) system in question. The issue is also subject to size and weight limits and indeed customer requirements.

However, in the research projects mentioned in this thesis we have seen several indications that the need for customisation often is smaller than expected (especially in research project E-3 in Table 3-a). It seems that the special requests of the owners of these large, capital goods are mainly connected to the layout at large (or the so called general arrangement in cruise ships) and the operating flexibility and reliability of their investment object. None of these should *per se* be an impediment to structural modularisation. In fact, it seems that the more established and productified a solution a supplier can offer, the more readily the customer is likely to adopt it. Conversely, if the supplier has not taken into account certain operational issues (such as maintenance availability), the more likely the customer is to suggest its own solution to the design problem, which makes it more difficult to use standard solutions. It is also common among owners to have special preferences regarding some major equipment of the systemic products. This is not a direct obstacle for modularisation, but rather puts pressure on the compatibility between different equipment used within the same systems. A parallel to Garud and Kumaraswamy's (1995) "economies of substitution" could be made here (see section 2.2.5).

However, what often seems to be an impediment to further modularisation is the purchasing function. Quite naturally purchasing is a function where costs can be easily cut by competing suppliers against each other. In the ship case, there were indications that this had led to a situation where sub-supplier scopes were seldom repeated from project to project. As a consequence there were low incentives to develop standard units and "repeatable solutions" (Davies and Brady, 2000). In the energy case there were similar occasions where the design and the manufacturing of certain equipment were split up between different parties or where the equipment belonging to the same larger system were bought from different suppliers in order to lower procurement costs. Whereas there undoubtedly are good reasons for doing so, it at the same time prevents the delivery as a whole from achieving a higher degree of standardisation and modularisation. Therefore there were in both the ship and the energy systems case a big interest in the recent developments towards systems sourcing/supply in the automotive industry; that is, to move modularisation to a higher hierarchical level.

5.2.2 Managing complexity – the function aspect

The interest in moving towards larger scopes raises the issue of how to divide a project between suppliers; in other words, the issue of task partitioning (von Hippel, 1990). Whereas there are different rationales for the partitioning of tasks or the decomposition of a product, it seems only reasonable to start off by looking at the product architecture (see e.g. Henderson and Clark, 1990; Ulrich, 1995; Sanchez and Mahoney, 1996; Novak and Eppinger, 2001). In both the studied cases we have looked at rather large entities and it may therefore be more appropriate to talk about studying the systems architecture. For the purpose we used the design structure matrix (DSM). One of the aims with the use of the DSM was to, following Sosa *et al.* (2003), identify and separate between "modular systems" on the one hand and "integrative systems" on the other. The underlying idea was that modular systems could be managed in isolation, definitely should be managed as wholes and that they therefore constitute potential sub-scopes within the main deliveries. The integrative systems in turn need more attention in terms of integration and coordination and might for instance not be as readily outsourced. The series of DSM-figures in chapter 4 show that Sosa *et al.'s* conceptualisation is useful and worthwhile in the large, system product context as well, although, as we might expect (see Hsuan, 1999), the interdependency seems to be higher the higher up in the system hierarchy we go.

The idea with modular systems does not neglect the importance of the preassemblies and building blocks. Modularity at one level of the system hierarchy does, however, not automatically imply modularity at another level. The idea in the case projects has been to identify systems scopes such that a supplier (whether it is internal or external) of them would be given the freedom to develop ready concepts for these sub-systems in isolation, in a way that makes most sense in the given situation. As a consequence, a ship or a power plant could readily be configured from more or less standard sub-system concepts, which at their level constitute "dominant designs" (Utterback and Abernathy, 1975) and platforms. This idea is thought to promote the development and use of standard, modular units at this sub-system level. In other words, the supplier is given the freedom to decide on the internal interfaces (Chen and Liu, 2005) and is expected to do so to enable the use of more standard solutions in the delivery. One could say that the wish is to be able to configure customised sub-systems from standard parts.

This is in slight contrast to the prevailing idea of modularity, where (standard) modules are seen as black boxes that conform to standard interfaces while no specifications are set on the interior of the black box (Baldwin and Clark, 1997). This prevailing idea, however, perhaps mainly applies to software engineering (and not entirely as well to e.g. mechanical engineering) and is also a matter of how we perceive the product hierarchy. Still, the use of standard building blocks is imperative for sustained profitability of many project businesses. In many cases such building blocks are either available on the market or can be productified so that they become available on the market. Whichever way, the idea is that the novelty and uniqueness shall not stem from the use of customised parts, but is rather seen at the higher system or overall product level.

Typical integrative systems in both cases were control systems and civil works/constructions. On the basis of our pre-assumption we would have suggested that these systems be such that the systems integrator might want to keep under its own control (e.g. in house). However, control systems are typically a product of specialised suppliers and the required competence is not easily acquired for a supplier specialised in e.g. mechanical engineering. In power projects, civil works are a sub-project that owners (buyers) for some reason often carry out themselves and are therefore not always included in the scope of a main contractor. In the ship case, on the other hand, civil-like works, such as building the cabin area or outfitting restaurants and theatres, are among those activities that have been contracted to sub-suppliers on a system or section/area (or rather function) basis. Still, as we saw in section 4.2, these areas are integral wholes (that is, integrative as wholes). In this case the benefit in analysing the system structure largely lies in learning about the interfaces, which I shall further discuss in section 5.3.

Integrative systems are also "core systems" (Tushman and Murmann, 1998; see section 2.2.7), such as the reciprocating engine in diesel or gas power plants (for a "thick description" of the engine in power projects, see Lindahl, 2003) and in ship power systems, and the boiler in steam power plants. Although being integrative, most of these core systems also show modular characteristics, largely because they are among the most productified equipment of respective delivery. The modular characteristics are especially obvious in their specified (if not standardised) interfaces. "Peripheral systems" (Tushman and Murmann, 1998) cannot be readily identified solely using the DSM.

Another argument for further modularisation and scope enlargement is the many auxiliary and connecting parts the bigger systems need for proper functioning[1]. Such parts are often gathered under labels like “balance of plant” (notably in power projects), “auxiliary systems”, “auxiliaries” or simply even “other systems/materials”. The potential problem with these parts is that they might become the responsibility of nobody and thus finally demand more attention than their relative importance in and value of the delivery would suggest. Consequently, there is a point in striving to incorporate those parts in systems scopes where they for one reason or another can be considered to belong. This might give a contradictory sense of ‘integrativeness’. This is again merely a matter of which level in the system hierarchy we are looking at. Modularity in this sense resides in the external, upper level interface. The so formed modular system may then internally be either integral or modular (i.e. looking down the system hierarchy). The main point persists: no equipment, be it modular, integral, integrative, supporting, connecting or auxiliary, shall be left outside the system boundaries; everything belongs somewhere. In fact, one could argue that this is what distinguishes “modularity in production” from “modularity in design”, that is, the ‘modularisation’ (read construction or assembly) of a module from the modularisation (i.e. decomposition) of a whole product.

In some cases also seemingly integrative systems can be allocated to corresponding modular systems, thus reducing the overall integration effort. Following this thought, for example every pipe connection between two machines (or sub-systems) would be seen as belonging to either or of the machines, or cut in half and split between the two machines. Alternatively, if the pipe connection is big enough it might be considered a (modular) sub-system of its own. The same goes for many civil structures (e.g. foundations). Although civil works (now mostly referring to the energy case) are often considered a project of its own (maybe partitioned in sub- and superstructures), many of these structures can be directly allocated to the machines (or sub-systems) they serve and support. It would, of course, make little sense to lay a separate foundation and build a separate weather shield for each and every machine on a power plant, but there definitely is a point in at least thinking in terms of such functional wholes. Obviously, the issue of so called “function sharing” (Ulrich and Seering, 1990), where two or more functions share the same structure (or are embedded in the same structural body), has to be decided from case to case. In the energy case there was in fact at the time of the study a debate as to whether the so called super structures shall be integrated or separated from the rest of the plant. There are indeed advantages and disadvantages with both options. What at least appears to be a sophisticated compromise, is to make a distinction between primary (separated from the rest, but serving needs of the whole plant) and secondary (serving

---

[1] This is a notion I got together with my colleague Magnus Gustafsson in a research project we were engaged in.

and supporting more directly specific equipment) structures. Taken together, this may serve as a demonstration of the ambiguity, or rather degree of freedom, associated with task partitioning.

In fact it seems that the higher up the more ambiguous is the case of task partitioning and modularisation. At lower levels it seems fairly clear how to construct the modules. On the higher levels business and industry specific conventions start to influence the choice of partitioning principle. For example, there are certainly some benefits with the idea of "thinking in terms of functional wholes". One issue complicating this idea is the fact that many industries have a long tradition in discipline-wise task partitioning: civil works are carried out by civil engineers, mechanical works by mechanical engineers, electrical works by electrical engineers etc. In companies where this tradition has been followed for long, the way of working according that principle has been fine-tuned, although it from another perspective would not be optimal. In the ship case a transition from discipline-wise (or field-specific) to function-based (or area-) contracting has been taking place during the past decade. This indicates that the same might be possible and even feasible, at least to certain parts, also in the energy case. This is likely to be even more so when we incorporate the process dimension (in the next few sections).

Based on my studies of the product DSMs, I conclude that managing complexity by introducing modularity in the system structure is at least technically a viable strategy. Following this, the question of "modularity in organization" can hardly be avoided. Taking the idea of modularity from the product architecture further to the organisational level is possibly even more intriguing an endeavour, however, in many senses also more difficult. I will continue the discussion on this issue in the next section (5.3). The same goes for the finding that part of the 'good' of the system level is that the system as a whole is much easier to handle than the bunch of smaller components it is made of.

Before discussing these issues in greater depth I will in the next section explore the 'excellence' of a module in the light of the process (or task) interfaces.

5.2.3 Managing products – the functionality aspect

The functionality of a product is nowadays often studied under the label of life-cycle engineering. This process dimension is also included in the theoretical framework set up for this study (see Figure 2-5). This dimension basically entails two issues frequently addressed by academia: first, the behaviour of the product throughout its life-cycle (Ishii, 1998; Gu and Sosale, 1999) and second, how well the information regarding the requirements of different life-cycle stages are passed on, received and taken into account between the different phases; in other words, the issue of e.g. the design-manufacture or other such interfaces (von Hippel, 1990; Adler, 1995). Quite naturally, the former is mostly studied within the engineering design discipline and the latter typically in the management science or operations management domain. Consequently, the former issue is typically concerned with (the optimal) structure and form, and thus mainly addresses "modularity in production" and "modularity in use" through a set of "design for X" principles (Ishii, 1998). Whereas I acknowledge the importance of that viewpoint, it has not been the primary focus of my investigations. From my therefore limited experience from the cases, I can merely support the view of e.g. Ishii (1998) and speculate that the maintenance (and operation) perspective might call for more attention in the kind of large, systemic products I have studied, given their exceptionally long life-time (e.g. 30 years). However, the interface and management point of view has been the one of the prime foci in the empirical part of this thesis and shall therefore be further discussed below (recognising the fact that this at the same time takes us closer to the second research question).

If we consider all the processes along the life cycle of the product (module or system) in Figure 4-19, we get a good idea of the amount of product and organisational interfaces in a project (in addition to the design/manufacturing interface mentioned above). This has at least two apparent implications. First, all the product and organisational interfaces are to be handled by the project management. From this it is easy to see that such 'component integration' and task coordination requires a major effort and often becomes the preoccupation of project management. From this perspective a 'good module' will be one that means project management has to handle fewer interfaces. This is indeed even more so if we decide to modularize the process side or embed the process in the product (see below).

Second, as the final cost of the product accrues as a result of its 'journey' through the value stream (life-cycle), only considering direct purchase or manufacturing cost provides a very limited view of the cost of a product. Still, as the process is cut (or partitioned using von Hippel's vocabulary) at each organisational function, it might be very hard to assess the total acquisition cost. Moreover, the true requirements for each phase or task are not always known in the preceding phases. This then of course requires a considerable integration and concurrent engineering efforts which are not always easy to handle. These considerations raise the question of how we actually should look at modules (or products at large). Namely, modules can be said to exhibit a totally different character fulfilling a different 'function' in each phase. In fact, the separation between the product and the process is philosophically not that easy (cf. Wittgenstein, 1953) and the meaning of words). Basically, we could think that these characteristics should, as far as possible, be embedded in the product. For some characteristics this is not viable. Those characteristics then have to be addressed in the process 'behind' the modules. This all, in turn, provides an opening towards the topic of service management. Due to the extensive life-cycle phases it might prove beneficial not to regard the modules as purely physical ones, but as such "activity-based offerings" that Normann and Ramirez (1993) call for. In addition to the physical modules, tangible services such as documentation, commissioning and operation, as well as more intangible services such and time and quality elements should be considered. This could for instance imply the development of what could be termed 'intangible modules' in connection to the physical modules. As a result, we should be able to continuously configure the deliveries according to the needs in each phase or according to changing customer wishes.

To summarize then, a 'good module' is more than just building blocks and preassemblies and function-to-component mappings. For large, systemic capital goods it should rather be seen as an internally integrated (although not necessarily integral) but externally modular system of associated functions and activities/services. In this sense, a physical module on its own is not as 'good' as when accompanied with required auxiliary functions and supporting or enabling services. Such a view is supported by Robertson and Ulrich's (1998) definition of a platform "as the collection of assets shared by a set of products". As such assets they include components, processes, knowledge, and people and relationships. This clearly takes us "beyond tangible building blocks" (see Hellström and Wikström, 2003a).

5.3 How modularity changes the delivery process

As said, the second research question was already addressed in the discussion on modularity in different stages of the project in the previous section (5.2.3). In addition, the answer to Q2) is searched for in the descriptions in sections 4.1.6 and 4.2.6, and to some part in the literature review on project business in chapter 2.

5.3.1 The concept set up

As explained above, integrative systems entail an increased integration and coordination effort. Whatever hierarchical level a module is situated at, it is after all only a part of a larger whole and eventually has to be integrated with the rest of the 'meta'-system. Consequently we can derive a need for so called "integrative design" (Wikström *et al.*, 2004), following the notion of an "integration team" in McCord and Eppinger (1993), in order to avoid the risk of sub-optimisation.

It is not only design that requires integration; the need for integration (or coordination) exists throughout the project life-cycle. Purchasing (one of the functions that is expected to change the most with the introduction of systems supply), transportation (including packaging, collection, shipping, road transportation and on site logistics), site construction and installation, and commissioning all have to be coordinated. This kind of functional or line management is actually the organisational form that prevails today, also in the studied cases: the engineering department designs, the purchasing department procures and so on. My research suggest that companies delivering large systemic goods in addition to this kind of organising adopt a life-cycle view of their part systems so in order to bridge the gap between the different phase interfaces and not to lose sight of the system as a whole (compare with Figure 4-24 and Figure 4-25). For instance, the function of a product or system manger could be to keep track of the system through out the process (life cycle). Alternatively, the system could be sourced from a sub-supplier as a whole, giving that supplier a turnkey responsibility for the system.

This above articulated view lays the foundation for the shift from “modularity in design” to “modularity in organisation” indicated in the previous section (5.2.2). It can be argued that project-based industries need certain flexibility to cope with the uncertainty, complexity and discontinuity inherent in their business and that such manoeuvrability can be achieved by a product and organisational structure based on modularity (see also Hellström and Wikström, 2005b). Physical (and organisational) structure is, however, not enough. In addition there seems to be well grounded need for certain intangible (and preferably modular) elements (processes) in connection to the modules as discussed earlier in this chapter. Furthermore, the whole palette of modular entities has to be integrated and coordinated through a set of managerial actions. While the next section will dig deeper into what such actions include, the concept set up for a modular delivery projects is shown in Figure 5-4.

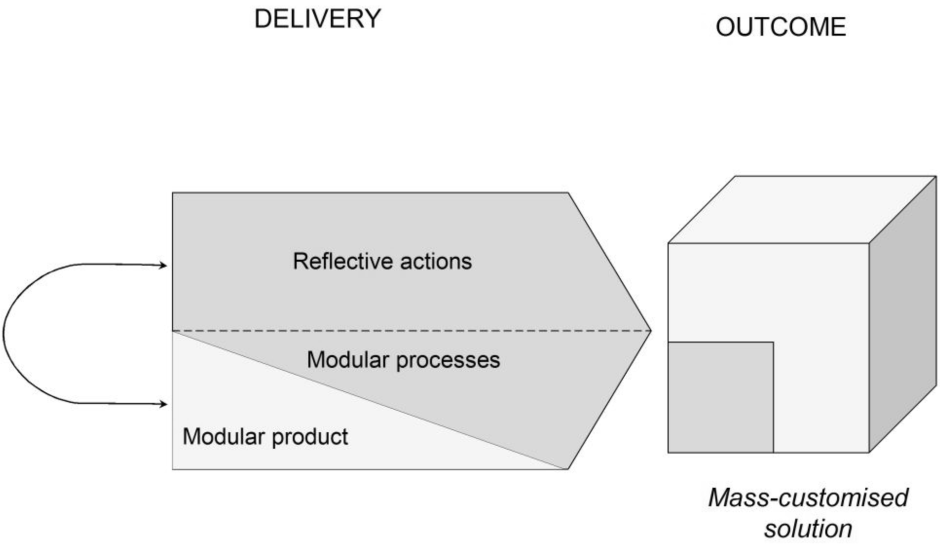
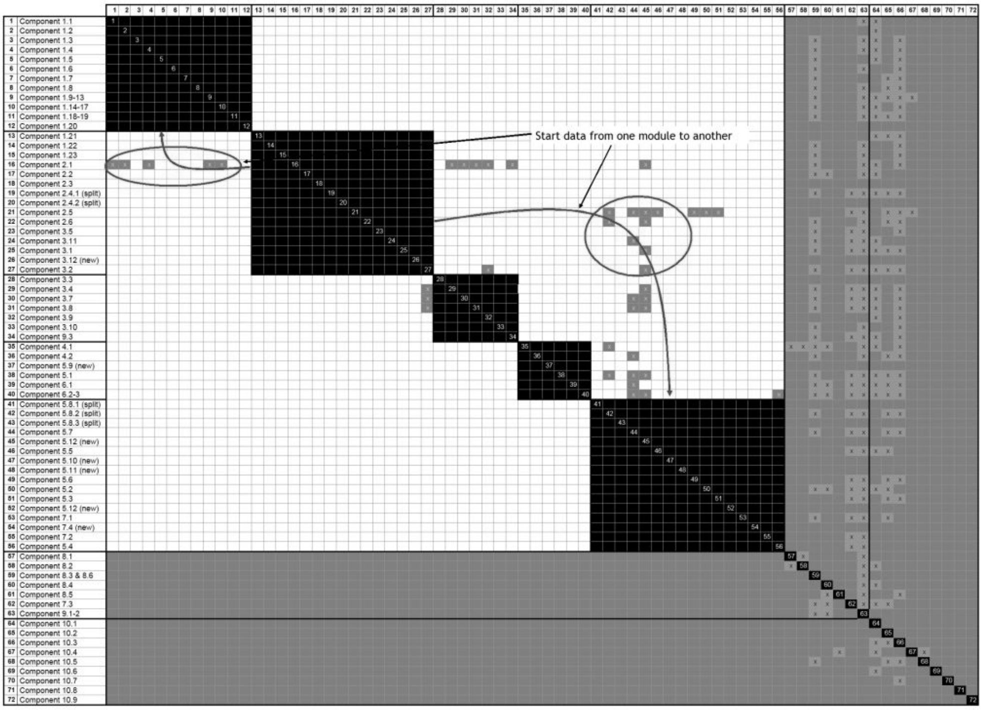


Figure 5-4 A framework for the management of modular project deliveries (for more information, see Hellström and Wikström, 2005)

5.3.2 Project management – focusing on interfaces and relationships

In my view the task of project management then is to coordinate the obtained palette (or WBS if one likes) as a whole, both horizontally and vertically, but only to appropriate parts. Following the notion of "information hiding" (Parnas, 1972; see also Baldwin and Clark, 1997) such appropriate parts are (a) the modular system interfaces (Chen and Liu, 2005), (b) partly the integrative systems and, if needed, (c) the interfaces between the organisational line functions (unless these are well established with routine information exchange, in which case they hardly need rigorous coordination). The idea for the first two categories (a) and (b) is illustrated in Figure 5-3, where the modular systems in Figure 4-21 have been painted black and the integrative systems are marked with grey.



Copyright PBI research Institute 2005

Figure 5-5 A schematic perception of "black boxes" using the DSM

While this resembles the concept of "interface management" that Sundgren (1999) introduced in the case of new product platform development, here it rather shows the tactical dimension of interface management in delivery projects. Moreover, it can be observed that the modules exhibit different interfaces from phase to phase (compare e.g. Figure 4-10 and Figure 4-11 in the ship case, and Figure 4-22 and Figure 4-23 in the energy systems case) as already discussed in section 5.2.3. This may not be surprising, but strengthens the notion that while a module as a physical building block is a fairly unchallenged fact, it shows a dynamic character seen as an information object, i.e. as a social construction if one like. If one still remains at the module boundaries set based on the product structure analysis, it means that the physical building block remains the same, whereas the informational interfaces varies from phase to phase. This can be compared with parents raising a child: whereas it undoubtedly is the same child from period to period, it asserts at times very different requirements on the parents in each period[1]. This provides a somewhat challenging view to the ideas reached in studies of other kind of projects that different life-cycle stages need different kind of product decompositions, that is, the use of multiple breakdowns depending on the use of the product (read: the phase in production); see, in the case of a new particle accelerator Hameri and Nitter (2002), and in the case of the automotive industry Sako (2003) and Takeishi and Fujimoto (2003). Mainly, my research tends to support this perspective on product decomposition. However, I call for attention to seeing (and managing) modules as functional wholes throughout the project life-cycle and show what such a viewpoint takes in terms of project management as depicted in Figure 4-24 and Figure 4-25. This notion is especially important in integrated solutions provision (see section 2.10.2), where the products consist of both goods and services and where the supply base consists of both internal and external actors. In that case, modularisation may serve the purpose of dividing the integrated solution into manageable and consistent parts. Incorporating the delivery aspect (other parts of the value stream than design) in the module characteristics, we might in addition to "economies of recombination" (see section 5.2.1) expect some kind of "economies of repetition" and thus take one step closer to the realization of "repeatable solutions" (Davies and Brady, 2001).

The DSM is generally seen as a tool for project management and has proved its usefulness for planning activity sequences, especially in order to reduce iteration loops (Eppinger, 2001). Some loops were identified in Figure 4-22 and Figure 4-23[2]. In innovation projects these loops generally serve to improve the product, but can also, if handled too loosely, adversely affect the time schedule of a project (Eppinger, 2001). In the delivery projects we have studied, the existence of such loops can in fact be taken as an indication of an unclear product and/or information structure and should therefore be avoided if possible (as is obviously the case in Figure 4-23). Indeed, on all points it might not be possible to eliminate the loops. In those cases it is instead important to acknowledge and actively manage them. Whereas the DSM is identified as a useful tool for project planning and handling iterations, its application in project scheduling is still limited (Maheswari and Varghese, 2004). This thesis does not explicitly address the scheduling problem, but provides a sketch of the basic idea of 'modular' project scheduling in Figure 4-25.

So far the model for project management advocated in this section, or the overall business concept articulated in this thesis, builds on a set of more or less 'rationalist' devices as "modularity in product and process architecture" and "modularity in organisation". Part of the benefit of these devices applied at the sub-system level is

---

[1] I acknowledge that this example belongs to my colleague Magnus Gustafsson. The whole notion of seeing 'modules' as "dynamic information objects", has developed in discussions between him and me.

[2] Although the loops are exemplified through the energy case, they are very likely to be present in the ship case as well (see the corresponding DSMs from the ship case).

that the system as a whole becomes much easier to handle. However, to be successful in practice they have to be coupled by some managerial notions explicated at the end of section 2.7. In Figure 5.4 these notions are gathered under the label of 'reflective actions'.

Summing up, one could say that having structured products and processes does not render the project management function unnecessary. I contend that the improved structures frees some time for project management from creating the product and instead enables it to better focus on the customer and other relationships, or rather the project environment at large.

5.3.3 Make or buy – an irrelevant question?

Modularity in organisation inevitably raises the question of vertical integration and outsourcing. Historically, we can see that ship building (at least in the studied case) has been a considerably more vertically integrated business than the energy systems business in general. Consequently, in the ship case we may speak of direct outsourcing with regard to the studied systems. In both cases, however, the development described in this thesis is more a question of identifying reasonable scopes and thereby an aggregation of minor equipment and sub-systems into larger function-based systems. Still, the systems structure analysis provides a better basis for making decisions on outsourcing without presupposing the necessity of that. In other words, while my findings do not directly speak to the issue of vertical disintegration, they certainly do support decentralised value creation, realised in one way or another.

There might actually be very good, strategic reasons for not outsourcing a system, depending on e.g. the technology dynamics in question (Brusoni *et al.*, 2001). Indeed, recent developments within the automotive sector, whose European and American representatives once were seen as the forerunners and proponents of the OEM[1]-model (Sako, 2003), now seem to be pulling parts of the production back inwards (Ojanperä, 2004). This seems to be so at least when it comes to electronic control (and other) systems, which earlier were embedded in the equipment or systems supplied to the OEM. Now the aim according to Matti Juhala is to separate the software and the hardware (Ojanperä, 2003). Similarly, Brusoni *et al.* (2001) argue that systems integrators cannot afford to lose sight of the technological development at the sub-system level, especially when it comes to systems where technological evolution is rapid. Control systems and electronics are furthermore probably among the systems that are considered to contain most value creation potential in the near future. Similar indications regarding the importance of the control systems could be found in the cases I studied.

---

[1] Original Equipment Manufacturer.

Nevertheless, because much equipment in the sectors have always been sourced from outside, it makes sense to merely aggregate the equipment to one system scope and assign the total responsibility for it to a first tier supplier. This kind of a suggestion raises one major concern among practitioners: the fear that this kind of arrangement merely serves to accumulate margins upon the original prices and that the price increase runs out of control due to the absence of competition. One can hardly dismiss this concern as irrational, quite the opposite. Clearly speaking, however, there seems to be two so called ideal types here. The traditional one, where suppliers are not seen to add any value, but rather should be held at arm's length and competed against each other so in order to reduce purchasing cost to a minimum. The other one is often termed "business partnership" or similar and seen to build on long-term and deepened relationships, where benefits are developed for both parties. Both entail advantages and disadvantages and are extensively studied (see e.g. Gadde and Snehota, 2000), why I will not comment the issue anymore than by saying that the approach advocated in this thesis very much counts on the latter.

In conclusion, the proposed concept does not entail outsourcing of manufacturing, since it is not a decisive issue and much equipment is already sourced from outside. However, what becomes outsourced (given that equipment comes from outside in the first place) in the model, is part of the design and project management (and installation in the ship case). These are functions that until quite recently in both cases have been almost entirely kept in house.

6 CONCLUSION

This research project set out to answer two research questions. In this chapter I shall explicate what kind of answers to them I have been able to provide, that is in general, assess how well the objectives of the research were met. I shall also try to crystallize the findings as to what kind of a theoretical contribution I want to put forward and what especially I like managers to learn from them. Finally I will reflect upon some methodological issues and outline the research agenda I see emerging from this research.

6.1 Closing the 'black box'

In brief, the main findings of this thesis are:

- Modules have been used within project-based industries for a long time. However, the traditional use of the concept mainly seeks production benefits. Per definition, modularity is a means for managing complexity. So understood it might prove more advantageous than merely as a production strategy. Considering different (hierarchical) levels of modularisation is key in making that shift.
- Considering the different phases of a project is imperative for successful structuring and management of modular products; in a project modules are more than building blocks, they are functional units that affects both the rest of the product and the process.
- One of the biggest benefits of modularity in project business is clarifying the interfaces between different parts within the product and between the different parts of the product and the processes, and consequently, between different organisational units.
- When modularity is considered over the entire product, at different hierarchical levels of the product and throughout the delivery phases and processes, it provides a means for managing the whole delivery of big, complex products at large. Modularity is then used as a strategy for both decomposition and integration.

As a conclusion, these findings give rise to a framework for the management of a complex system deliveries based on the notion of modularity, in other words, a framework for the structuring and identification of one's product. The elements of the framework are explicated below.

The first research question focused on module characteristics in projects with the underlying, general aim to provide a guideline for an increased use of modularisation; i.e. how to get 'there'. The answer to this question was partly derived from extant literature in both engineering and management. This theoretical framework was then applied on the two empirical cases. First, it was concluded that the current way of utilizing modularity mainly hinges upon the notion of "modularity in production" (see Baldwin and Clark, 2000; Takeishi and Fujimoto, 2003). The aim with this approach is to isolate some production work so as to move this work away from difficult conditions on the construction site to a workshop (compare with Hayes and Wheelwright, 1979) by preassembling some of the material. If possible the same preassembled units are used from project to project, thus providing an opportunity to reap some kind of economies of scale.

The importance of this 'structural approach' is not disputed. And although it to certain parts agrees to the function-to-component criterion it was found that a stronger focus on "modularity in design" (see Baldwin and Clark, 1997; 2000) might prove beneficial. As a consequence we chose to follow Sosa *et al.'s* concept of modular and integrative systems. It was shown that a corresponding 'modularity in systems architecture' constitute a technically viable strategy for companies creating and delivering large, systemic capital goods. Although the system concept in a technical sense is not always entirely appropriate in ship building, compared to section- or area-based scopes, the power of the modularity in design approach lies in clarifying the interfaces between different sections, areas and systems (we can, however, also think of these as functions). When the same 'function' scopes are used from projects to projects so called "economies of substitution" (Garud and Kumaraswamy, 1995) or, in projects rather, "economies of recombination" (Grabher, 2004) are likely to occur.

Obviously modularity in production and modularity in design are pursued at two quite different "levels of modularization" (see Hsuan, 1999), which in many ways has become a key concept for my studies. While modularity at the system level does not directly imply modularity at the building block (module or preassembly) level, my belief is that clarifying the "design rules" (Baldwin and Clark, 1997) or "external interfaces" (Chen and Liu, 2005) of a system, thereby striving to isolate it as a modular system, gives better opportunities for the development of the interior of the system. This development could then work in favour of the use of more standard units and design solutions. In general, it seems that the higher up in the systems hierarchy we go the more interdependencies between systems we find and, when it comes to decomposition and partitioning principles, the stronger is the influence from business and industry specific conventions. This agrees with the general belief that the lower down the system hierarchy we go the more standard the components are (see e.g. Artto *et al.*, 1998).

A larger, modular system scope is also likely to improve the possibility to arrange the activities associated with it in an optimal manner, or rather, a more reasonable manner (see Toulmin, 2001). This argument emerges from the somewhat philosophical notion that a product (and a module or a system) is a product only when used as a product, but that a product changes character and fulfils a whole series of different functions during its life-time. As a consequence, a module should not only been seen as the tangible building block or system it physically confines to. Neither shall the activities merely be grouped under the label of services. Instead we should look at the modular systems as function-based entities (function understood both in a technical and an organisational sense). This way we can best assess the benefit of a module seen from a life-cycle perspective (including the life-cycle cost of it). We could call this a further transition from modularity in design to "modularity in organisation" (see Baldwin and Clark, 1997; Langlois, 2002). Now, when used from project to project, turnkey or "integrated solutions" deliveries induce a kind of "economies of repetition" (Davies and Brady, 2000; Brady and Davies, 2004), where not only the same physical modules are reused, but the same (modular) way of working is repeated.

The second research question probes into the outcome of the first and entails an interest in how the modular product then ought to be delivered as a whole or more precisely, how the delivery ought to be managed from the systems integrator's or solution provider's point of view; i.e. how to be 'there'. The function- or modular system-oriented way of looking at project deliveries is in slight contrast to the typical way of managing project companies, which is done by dividing up the delivery chain into line functions. My findings do not suggest that project companies necessarily should move from a line-function model to a system-based model. However, they do call for a change in mode and perception. When such a change is realised "clarification", or in other words, reducing complexity (see Miller and Elgård, 1998), is likely to be one of the biggest benefits of modularity in the studied context. This is thanks to the significantly reduced interfaces (both technical and organisational) a project manager has to handle.

A modular delivery does, however, not leave the project manager unemployed. The way to manage the delivery set up outlined by the answer to the first research question is to assign full freedom and responsibility for the sub-scopes to respective suppliers (or organisational units). The delivery as a whole is then coordinated at the intersecting points (that is, the external interfaces outside the "black box"), which although being different from phase to phase belong to the same confined 'module'. The time that is released when moving from component integration and task coordination to systems integration and scope coordination, can beneficially be used for screening the project environment and managing the relationships in a project.

In essence, modularisation is about decomposing a final whole into smaller parts. At the end of the day the parts need to be integrated back into the whole. Why then modularise? Modularisation is pursued merely because it makes it easier to reach the final whole (given that it is a long way there). Modularity, however, increases the risk for sub-optimisation, or the pursuit of local optimisation instead of global (Ulrich, 1995). To avoid this, something what we could call phase integration is needed, that is for instance: integrative design teams and transportation coordinators. This concurs with Ron Sanchez (2003) who contends that modularity is a way of managing and organising at large as much as a design strategy. Hence, one could, based on the findings in this thesis, launch yet one more "modularity in X", namely 'modularity in management".

6.2 Theoretical contribution

The general contribution of this thesis lies on the one hand in trying out the concept of modularity in a new context, the project business context, and on the other, in challenging the traditional, centralized way of managing big projects. In other words, this thesis provides a synthesis of the ideas of modularity and project theory. In this sense, the thesis can also be said to extend to the concept of modularity by attaching the processual or value stream elements to it and by incorporating the organizational and managerial dimension. Further than that, I maintain that the message and contribution of this thesis lies in the exhaustive discussion in chapter 5. It does not always serve the purpose to summarize the conclusions into a few lines of text. I shall thus here comment my findings in more detail only to those parts which either have been sparsely explored earlier or which I challenge.

My study on modularity in the creation and delivery of large, systemic capital goods furthers the academic path outlined by especially Hobday (1998), Wikström (2000), Brusoni and Prencipe (2001), Prencipe *et al.* (2003) and Davies (2004). I specifically show that while modularity in production is a since long pursued strategy, modularity in design (notably system architecture) is a level of modularisation that is not only from a project management point of view more reasonable, but also a technically and organisationally viable strategy. I furthermore argue that the line (or activity) oriented way of organising projects should at least be complemented with a product (or system) oriented view of the capital good to be delivered. This constitutes a new way of perceiving one of the perhaps most institutionalised project management tools, the work breakdown structure. Deriving from the urge to see products and processes as one, the concept of a "functional module" is coined in this thesis (that is, not just function-based module, but a module containing both a function and functionality). Perhaps the largest contribution in the end is the development of a new framework for the management of a modularised delivery (explicated in the previous section).

6.3 Practical implications

6.3.1 General implications

Modularity in project business is perhaps most of all a means for understanding one's own product and how it connects to other parts of a system. This thesis encourages companies in the business of creating and delivering large, complex capital goods to 'go modular'. Moreover, it describes how this can be achieved and pursued as a business concept. As the elements of the proposed concept should be clear from the discussion in chapter 5 and the summary of the findings in section 6.1, I shall not repeat them here. Shortly and very concisely put, in this thesis I urge companies to re-consider their product and process structures to see how they can benefit from modularity. I advocate modularity as a means for managing and organising the whole delivery. I thus urge managers to think in terms of aggregate functions, appropriate levels of breaking down their deliveries in sub-functions, interfaces, and coordination and integration. This is especially important these days when manufacturing continues to move to low cost countries and the formerly industrialised countries have high expectations of the service and knowledge economy. As for the systems integration of large capital goods we can, together with Keith Pavitt (2003), conclude that that is where "manufacture and services still meet". Next I shall pinpoint some challenges with the proposed model.

6.3.2 Challenges with the proposed concept

> *And it ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. Because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new.*
>
> Niccolo Machiavelli, *The Prince*[1]

In the spirit of Machiavelli, I maintain that the implementation of the proposed new concept is likely to constitute the greatest challenge with it. Despite all diagnoses and analyses there will be little worth in the concept unless it can be taken further in the action research cycle. While there may be many technical issues and organisational challenges to face I will focus on three of them that clearly can be identified from my studies: the changing project management function, the customer integration process and supply management.

First, there is the issue of getting project managers that once used a hands on approach to cope with a delivery where they are not supposed to engage in what has been called 'micro management'. This might be very hard and maybe even demand a different type of project managers. As much as it is a question of education and training, it probably also is a question convincing project management that they can rely on the systems suppliers to carry out the 'micro management'.

Second, companies striving to gain full benefit from the concept need to train their sales people how to sell "repeatable solutions" (which for instance might entail involving suppliers in the bidding). My studies partly indicate that the demand for customisation not always stem from the customer deliberately wanting a customised product. The customer is, of course, interested in gaining a competitive edge over its competitors and thereby wants something more than the 'standard' product. In addition to this, however, another of the owner's main concerns is the reliability of the solution. If the supplier cannot convince the owner of the reliability of his solution, the customer (or his consultant) is likely to suggest a solution of his own. In this regard a standard, proven concept might be beneficial.

Third, in the case that the 'module' is sourced from outside, supply management is bound to confront a whole series with challenges. First of all, a suitable supplier for the intended 'module' has to be found. When this is done (if it is done) the selected supplier has to learn to cope with an entirely new situation. In many cases it is the

---

[1] http://www.sonshi.com/mach6.html

final systems integrator that has to see to this and maybe even teach. This entails many things. The supplier has to learn to manage its new scopes which might require a lot in terms of project management. It also has to learn and establish routines to deal with its own suppliers, which maybe even more so than before as a result of aggregation. This entails the selection and pursuit of an appropriate (internal) interface strategy (Chen and Liu, 2005). Furthermore, it has to learn to deal with the discontinuity inherent in project business. This is just to name a few of the challenges a first tier supplier is likely to confront.

6.4 Methodological reflections

6.4.1 Credibility

The credibility (paralleling internal validity; see section 3.4) of my interpretations and conclusions are ensured through the close co-operation with company representatives. All results and reports have been presented and discussed together with concerned parties. This should to in part provide credibility for my research among the objects of the study. Admittedly though, one could still go further on the action research cycle (see Figure 1-3) or rather repeat the cycle in order to 'validate' the framework advocated in this thesis. This would, however, require another few years and thus lies beyond the scope of a doctoral thesis project (which of course does not mean that it should or could not be done otherwise). In my case I hence take the interest, engagement and positive reception of the participating company representatives as a sign of credibility towards the presented conclusions. Also the use of a widely established technique, the DSM, has promoted the credibility of certain parts of this research. Although I have not used mathematical means for modelling, simulating and finally arriving at an entirely rational and optimal decomposition of a project, I claim the suggested breakdowns to be at least reasonable (cf. Toulmin, 2001). This is in a practical sense often enough, if not even the best we can get given the myriad of variables and contingencies that otherwise would have to be included in a model.

6.4.2 Transferability

Transferability parallels external validity (Guba and Lincoln, 1998). As already maintained several times, this study does not primarily aim at generalisations to a broader population of so called project companies. This is the case in much 'qualitative' research. Instead, Guba and Lincoln suggest the message of the research be transferred to a potentially interested audience by means of convincing, rhetorical explication, notably through so called "thick descriptions" of the case at hand (Geertz, 1973) so as to help others learn from it and maybe even themselves determine to what extent the results can be transferred to their case. This study may not be particularly "thick" in the way Clifford Geertz meant, but still attempts to provide a thorough description of (a) different theoretical viewpoints on modularity, (b) the background and the purpose of, and the issues considered and the action taken in the research programmes this study is based on, and (c) the elements of a business concept based on modularity in the project-based industry, and how they nit together. Rather than pure verbal "thickness" the transferability of this report is thought to reside in the illustrations in chapter 4 accompanied with analytical comments and the synthesising framework explicated in section 6.1. As for potential industries or 'project businesses' to whom the descriptions, concepts and findings in this thesis might be transferred, I like to mention industries creating the kind of complex products and systems conceptualised by Hobday (1998; Acha *et al.*, 2004) and the kind of project-based industries described in Wikström (2000).

6.4.3 Authenticity

The catalytic (and tactical) authenticity (Guba and Lincoln, 1998) resides in the stimuli (and empowerment) to action that this thesis work has brought about in the applied research projects that this thesis is based on (see sections 3.2 and 3.3). This message of this thesis also bears another kind of authenticity: ontological and educative (Guba and Lincoln, 1998). These reside in the way modularity is articulated as a means for understanding and grasping one's own product and its connections to other parts of a system (see sections 6.1 and 6.3).

6.4.4 Implications for method

In this thesis I have sought to study the product and process structures mainly using one single tool: the design structure matrix. Whereas the DSM is an established tool (Steward, 1981; Eppinger, 2001), the novelty in my approach resides in (a) using the DSM for studying different phases of the project life-cycle (b) based on one single breakdown obtained from a product structure analysis. This has not gone without complications, but has also had certain benefits. The complications arise in particular from the fact that different phases simply follow different action and breakdown logics. The benefit is of course that the modular entity remains the same (while its boundaries may be shifting). Some kind of a combination of the activity and product based breakdowns might possibly prove to be a good solution.

Another difficulty is the huge data collection effort behind each DSM. One way to escape at least some of the problems in this issue would be to treat the dependencies between the elements of the product simply as ‘function dependencies’ (see Oosterman, 2001), instead of using the taxonomy with four or five interaction types (spatial, structural, energy, material and information) suggested by Pimmler and Eppinger (1994) and Sosa *et al.* (2001). The function approach would also resolve the problem with analysing and consequently weighting the different types of dependencies. In this regard, e.g. Oosterman’s (2001) taxonomy developed for the study of the links between engineering and organisational knowledge (the links between product architecture and organisational structure) might prove interesting. He suggests the use of three types of interaction: the functional type of interaction, the mapping type of interaction and physical interaction. However, the use of different kinds of taxonomies, or means for using the DSM at large, ultimately depends on the intended type of analysis.

6.5 Future prospects

I see many further research problems evolving from my findings. I shall, however, limit my suggestions to issues in strict relation to the topic of my thesis.

In this thesis I have indicated something like ‘it is all a matter of hierarchical level’. My investigation has dealt with the concept of modularity at a rather high level. The strategy has, so to say, been to start from above. The idea is that modularisation then should continue at the lower levels as well (only where found appropriate, of course). It would be important to follow the development to see whether this idea realizes and more specifically how and under what circumstances: Can so called dominant designs be achieved in project business? How does the discontinuous character of the business affect all this?

In my studies I have mainly focused on the supply side. Inquiring into a compromise between standardisation and customisation can hardly reach a fully exhaustive answer without considering the demand side as well. Future studies in e.g. the commonality between large but repetitive projects should therefore be undertaken and accompany the studies in product architecture. Moreover, as discussed in the thesis truly standard modules are difficult to attain in project business (at least on the higher hierarchical levels). However, when it comes to customisation, what would be important to know for many project companies is how changes to the sales design effect the further design process (at the basic and detail levels). In the energy case we received interesting indications of how this idea could be pursued in order to develop ‘standard’ conceptual offerings (see and compare with section 4.2.6).

In relation to the above, I have so far mainly considered the phases from design to installation. In the future especially the operation and maintenance phase, i.e. the issue of “modularity in use”, should be included in “business concepts based on modularity”.

It is often pointed out that it is totally different to be a system supplier or solution provider than a mere equipment manufacturer. Likewise, it is definitely different to purchase whole systems or solutions than mere equipment (cf. Flowers and Hobday, 2005). It is likely to be even more so if we talk about ‘function providing’ or ‘function procurement’. Starting from the issue of how to price and specify a solution/function (see e.g. Roegner, Seifert and Swinford, 2001) I take this to be one of the most urgent matters on the research agenda stemming from this thesis.

Finally, my studies merely provide one, however important, threshold lowering step towards ‘real’ business partnerships between companies. My approach is, however, fairly structural and technical. Still, many of the interfaces are realized by human action. There could hence well be merit in exploring the human side of “modularity in organisation” etc, which after all might be the determining part in the success of the proposed concept.

I have hereby invited scholars from various disciplines to join me in future investigations of these intriguing issues.

REFERENCES

Acha, Virginia, Davies, Andrew, Hobday, Michael and Salter, Ammon (2004): Exploring the capital goods economy: complex product systems in the UK, *Industrial & Corporate Change,* 13, pp. 505-529.

Ackoff, Russell (1979): The Future of Operational Research is Past, *Journal of Operational Research Society,* 30, pp. 93-104.

Adler, Paul (1995): Interdepartmental Interdependence and Coordination: The Case of the Design/Manufacturing Interface, *Organization Science,* 6, pp. 147-167.

Alasuutari, Pertti (1999): *Laadullinen tutkimus,* Vastapaino, Tampere.

Alderman, Neil, Ivory, Chris, McLoughlin, Ian and Vaughan, Roger (2005): Sense-making as a process within complex service-led projects, *International Journal of Project Management,* 23, pp. 380-385.

Alderman, Neil, Ivory, Chris, Vaughan, Roger, Thwaites, A. and McLoughlin, Ian (2003): *The Project Management Implications of New Service-led Projects: New Issues and Directions for Research*, Proceedings of the EURAM Conference, Milan, Italy, 3-5 April.

Alexander, Christopher (1964): *Notes on the synthesis of form,* Harvard University Press, Cambridge, MA.

Alexander, Christopher (1971): *Preface to the second edition of "Notes on the synthesis of form",* Harvard University Press, Cambridge, MA.

Alf, Martin and Menapace, Wolfgang (2002): Modular power Plants: Tailor-Made off the Rack - Competitive and flexible solutions for steam power plants, *Siemens power journal online,* May 2002, pp. 1-5.

Anderson, J. C. and Narus, J. A. (1995): Capturing the Value of Supplementary Services, *Harvard Business Review,* 73 (Jan-Feb), pp. 75-83.

Anderson, Philip and Tushman, Michael (1990): Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change, *Administrative Science Quarterly,* 35, pp. 604-633.

Andritsos, Fivos and Perez-Prat, Juan (2000): *The Automation and Integration of Production Processes in Shipbuilding,* State-of-the-Art report, Joint Research Centre, European Commission, Europe, p. 81.

Araujo, Luis, Dubois, Anna and Gadde, Lara-Erik (1999): Managing Interfaces with Suppliers, *Industrial Marketing Management,* 28, pp. 497-506.

Argyris, Chris (1995): Action science and organizational learning, *Journal of Managerial Psychology,* 10, pp. 20-26.

Artto, Karlos, Heinonen, Rauno, Arenius, Marko, Kovanen, Vesa and Nyberg, Tom (1998): *Global project business and the dynamics of change,* Technology Development Centre Finland (TEKES) & Project Management Association (PMA Finland), Helsinki.

Artto, Karlos and Wikström, Kim (2005): What is project business?, *International Journal of Project Management,* 23, pp. 343-353.

Baldwin, Carliss and Clark, Kim (1997): Managing in an Age of Modularity, *Harvard Business Review,* 75, pp. 84-93.

Baldwin, Carliss and Clark, Kim (2000): *Design rules: The power of modularity,* MIT Press, Cambridge, MA.

Bartleby.com (2004): www.bartleby.com/65/mo/module.html, retrieved 15.4.2004.

Bijker, Wiebe, Hughes, Thomas and Pinch, Trevor (1987): *The social construction of technological systems: new directions in the sociology and history of technology,* MIT Press, Cambridge, MA.

Blackenfelt, Michael (2001a): *Managing complexity by product modularisation: balancing the aspects of technology and business during the design process*, Doctoral thesis, Royal Institute of Technology, Stockholm, Sweden.

Blackenfelt, Michael (2001b): *Modularisation by relational matrices: a method for the consideration of strategic and functional aspects*, In Eds. Riitahuhta, A. and Pulkkinen, A.: *Design for Configuration - A Debate based on the 5th WDK Workshop on Product Structuring*, Springer, Berlin, pp. 134-152.

Blomberg, Jesper (1998): *Myter om projekt,* Nerenius-Santérus, Stockholm, Sweden.

Bonaccorsi, Andrea, Pammolli, Fabio and Tani, Simone (1996): The Changing Boundaries of System Companies, *International Business Review,* 5, pp. 539-560.

Brady, Tim, Davies, Andrew and Gann, David (2005): Creating value by delivering integrated solutions, *International Journal of Project Management,* 23, pp. 360-365.

Brusoni, Stefano and Prencipe, Andrea (2001): Unpacking the Black Box of Modularity: Technologies, Products and Organizations, *Industrial & Corporate Change,* 10, pp. 179-205.

Brusoni, Stefano, Prencipe, Andrea and Pavitt, Keith (2001): Knowledge Specialization, Organizational Coupling, and the Boundaries of the Firm: Why Do Firms Know More Than They Make?, *Administrative Science Quarterly,* 46, pp. 597-621.

Bryman, Alan (2001): *Samhällsvetenskapliga metoder,* Liber, Stockholm, Sweden.

Brännback, Malin and Näsi, Juha (2004): *Logic Concepts in Strategic Thinking,* Åbo Akademi University, Department of Business Studies, Turku/Tampere, Finland.

Budhraja, V. (1999): The Future of Electricity Business, *The Electricity Journal,* 12, pp. 54-61.

Buffa, Elwood and Sarin, Rakesh (1987): *Modern production/operations management,* Wiley, New York.

Burrell, Gibson and Morgan, Gareth (1979): *Sociological paradigms and organisational analysis: elements of the sociology of corporate life,* Heinemann, London.

Chandler, Alfred (1977): *The visible hand: the managerial revolution in American business,* Belknap, Cambridge, MA.

Chandler, Alfred (1990): *Strategy and structure: chapters in the history of the industrial enterprise,* MIT, Cambridge, MA.

Chase, Richard and Aquilano, Nicholas (1992): *Production & operations management: a life cycle approach,* Irwin, Homewood, IL.

Chen, Kuo-Min and Liu, Ren-Jye (2005): Interface strategies in modular product innovation, *Technovation,* 25, pp. 771-782.

Chesbrough, Henry (2003): *Towards a Dynamics of Modularity: A Cyclical Model of Technical Advance*, In Eds. Prencipe, A., Davies, A. and Hobday, M.: *The Business of Systems Integration*, Oxford University Press, UK, pp. 174-198.

Chesbrough, Henry and Kusnoki, K. (2001): *The Modularity Trap: Innovation, Technology, Phase shifts and the Resulting Limits of Virtual Organizations*, In Eds. Nonaka, I. and Teece, D. J.: *Managing Industrial Knowledge*, SAGE, London, pp. 202-230.

Clark, Alfred (1980): Action research: theory, practice, and values, *Journal of Occupational Behavior,* 1, pp. 151-157.

Clark, Kim (1985): The Interaction of Design Hierarchies and Market Concepts in Technological Evolution, *Research Policy,* 14, pp. 235-251.

Clark, Kim (1989): Project scope and project performance: The effect of parts strategy and supplier involvement on product development, *Management Science,* 35, pp. 1247-1263.

Clark, Kim and Fujimoto, Takahiro (1991): *Product development performance: strategy, organization, and management in the world auto industry,* Harvard Business School Press, Boston, MA.

Clark, Kim and Wheelwright, Steven (1993): *Managing new product and process development: text and cases,* The Free Press, New York.

Collins, Robert, Bechler, Kimberly and Pires, Silvio (1997): Outsourcing in the automotive industry: From JIT to Modular Consortia, *European Management Journal,* 15, pp. 498-508.

Cova, Bernard and Holstius, Karin (1993): How to Create Competitive Advantage in Project Business, *Journal of Marketing Management,* 9, pp. 105-121.

Cova, Bernard and Hoskins, Steven (1997): A twin-track approach to project marketing, *European Management Journal,* 15, pp. 546-556.

Cova, Bernard, Mazet, Florence and Salle, Robert (1994): From competitive tendering to strategic marketing: an inductive approach for theory-building, *Journal of Strategic Marketing,* 2, pp. 29-47.

Cova, Bernard, Mazet, Florence and Salle, Robert (1996): Milieu as a Pertinent Unit of Analysis in Project Marketing, *International Business Review,* 5, pp. 647-664.

Cova, Bernard and Salle, Robert (2005): Six key points to merge project marketing into project management, *International Journal of Project Management,* 23, pp. 354-359.

Dahmus, Jeffrey, Gonzalez-Zugasti, Javier and Otto, Kevin (2001): Modular product architecture, *Design Studies,* 22, pp. 409–424.

Davies, Andrew (1996): Innovation in Large Technical Systems: The Case of Telecommunications, *Industrial & Corporate Change,* 5, pp. 1143-1180.

Davies, Andrew (2004): Moving base into high-value integrated solutions: a value stream approach, *Industrial & Corporate Change,* 13, pp. 727-756.

Davies, Andrew and Brady, Tim (2000): Organisational capabilities and learning in complex product systems: towards repeatable solutions, *Research Policy,* 29, pp. 931-953.

Davies, Andrew, Brady, Tim, Puay, Tang, Hobday, Michael, Rush, Howard and Gann, David (2003): *Delivering Integrated Solutions*, SPRU-CENTRIM, Brighton, p. 34.

Davies, Andrew and Hobday, Michael (2005): *The Business of Projects - Managing Innovation in Complex Products and Systems,* Cambridge University Press, UK.

Davies, Andrew, Puay, Tang, Hobday, Michael, Brady, Tim, Rush, Howard and Gann, David (2001): *Integrated Solutions: The New Economy between Manufacturing and Services*, SPRU-CENTRIM, Brighton, p. 43.

Davis, Mark, Aquilano, Nicholas and Chase, Richard (2003): *Fundamentals of operations management,* McGraw-Hill/Irwin, Boston, MA.

Davis, Stanley (1987): *Future perfect,* Addison-Wesley, Reading, MA.

Denzin, Norman and Lincoln, Yvonna (1998): *Introduction: Entering the Field of Qualitative Research*, In Eds. Denzin, N. K. and Lincoln, Y. S.: *The Landscape of Qualitative Research: Theories and Issues*, SAGE Publications, Thousand Oaks, California, pp. 1-40.

Dickens, Linda and Watkins, Karen (1999): Action Research: Rethinking Lewin, *Management Learning,* 30, pp. 127-140.

Doran, Desmond (2003): Supply chain implications of modularization, *International Journal of Operations & Production Management,* 23, pp. 316-326.

Dubois, Anna and Gadde, Lars-Erik (2002a): Supply strategy and network effects — purchasing behaviour in the construction industry, *European Journal of Purchasing & Supply Management,* 6, pp. 207-215.

Dubois, Anna and Gadde, Lars-Erik (2002b): Systematic combining: an abductive approach to case research, *Journal of Business Research,* 55, pp. 553-560.

Duray, Rebecca, Ward, Peter, Milligan, Glenn and Berry, William (2000): Approaches to mass customization: configurations and empirical validation, *Journal of Operations Management,* 19, pp. 605-625.

Dvir, Dov and Lechler, Thomas (2004): Plans are nothing, changing plans is everything: the impact of changes on project success, *Research Policy,* 33**,** pp. 1-15.

Dyer, Jeffrey (1996): Specialized supplier networks as a source of competitive advantage: Evidence from the auto industry, *Strategic Management Journal,* 17**,** pp. 271-291.

Dyer, Jeffrey (1997): Effective interfirm collaboration: How firms minimize transaction cost and maximize transaction value, *Strategic Management Journal,* 18**,** pp. 535-556.

Eisenhardt, Kathleen (1989): Building Theories from Case Study Research, *Academy of Management Review,* 14**,** pp. 532-550.

Engwall, Mats (2003): No project is an island: linking projects to history and context, *Research Policy,* 32**,** pp. 789-808.

Eppinger, Steven (1997): *A planning method for integration of large-scale engineering systems*, Proceedings of the International Conference on Engineering Design, Tampere, Finland,

Eppinger, Steven (2001): Innovation at the Speed of Information, *Harvard Business Review,* 79**,** pp. 149-158.

Ericsson, Anna and Erixon, Gunnar (1999): *Controlling design variants: modular product platforms,* Society of Manufacturing Engineers, Dearborn, MI.

Erixon, Gunnar (1998): *Modular function deployment: a method for product modularisation*, Doctoral thesis, Royal Institute of Technology, Stockholm, Sweden.

First Marine International (2003): *Overview of the international commercial shipbuilding industry*, The European Community - Background Report, The European Community, Europe, p. 35.

Fleming, Lee and Sorenson, Olav (2001): The Dangers of Modularity, *Harvard Business Review,* 79**,** pp. 20-21.

Flowers, Stephen and Hobday, Michael (2005): *Why owners no less than they need to buy CoPS*, Working paper, SPRU-CENTRIM, Brighton.

Foote, Nathaniel, Galbraith, Jay, Hope, Quentin and Miller, Danny (2001): Making solutions the answer, *The McKinsey Quarterly***,** pp. 84-97.

Foster, M. (1972): An introduction to the theory and practice of action research in work organizations, *Human relations,* 25**,** pp. 526-556.

Fredriksson, Peter (2002): Modular assembly in the car industry - an analysis of organizational forms' influence on performance, *European Journal of Purchasing & Supply Management,* 8**,** pp. 221-233.

Gadde, Lars-Erik, Huemer, Lars and Håkansson, Håkan (2003): Strategizing in industrial networks, *Industrial Marketing Management,* 32**,** pp. 357-364.

Gadde, Lars-Erik and Jellbo, Oskar (2002): System sourcing - opportunities and problems, *European Journal of Purchasing & Supply Management,* 8**,** pp. 43-51.

Gadde, Lars-Erik and Snehota, Ivan (2000): Making the Most of Supplier Relationships, *Industrial Marketing Management,* 29**,** pp. 305-316.

Gaddis, P (1959/1991): *The Project Manager*, In *Project management (A Harvard Business Review Paperback)*, Harvard Business School Press, Boston, MA, pp. 29-37.

Galbraith, Jay (1973): *Designing complex organizations,* Addison-Wesley, Reading, MA.

Gann, David and Salter, Ammon (2000): In *Research Policy*, Vol. 29, pp. 955-972.

Garud, Raghu and Kumaraswamy, Arun (1995): Technological and organizational designs for realizing economies of substitution, *Strategic Management Journal,* 16**,** pp. 93-109.

Garud, Raghu and Kumaraswamy, Arun (2003): *Commentary (on "Technological and organizational designs for realizing economies of substitution")*, In Ed. Langlois, R.: *Managing in the modular age: architectures, networks, and organizations*, Blackwell, Malden, MA, pp. 68-77.

Geertz, Clifford (1973): *The interpretation of cultures: selected essays,* Fontana Press, London.

Gilmore, James and Pine, Joseph (1997): The Four Faces of Mass Customization., *Harvard Business Review,* 75**,** pp. 91-101.

Grabher, Gernot (2004): Temporary Architectures of Learning: Knowledge Governance in Project Ecologies, *Organization Studies,* 25**,** pp. 1491-1514.

Gray, Clifford and Larson, Erik (2000): *Project Management - The Managerial Process (International edition),* Irwin/McGraw-Hill, Singapore.

Grönroos, Christian (1994): From scientific management to service management, *International Journal of Service Industry Management,* 5**,** pp. 5-20.

Grönroos, Christian (2000): *Service management and marketing: a customer relationship management approach,* Wiley, Chichester, UK.

Gu, P. and Sosale, S. (1999): Product modularization for life cycle engineering, *Robotics and Computer-Integrated Manufacturing,* 15**,** pp. 387-401.

Guba, Egon (1981): Criteria for assessing the trustworthiness of naturalistic inquiry, *Educational Communication and Technology Journal,* 29**,** pp. 75-92.

Guba, Egon G. and Lincoln, Yvonna S. (1989): *Fourth Generation Evaluation,* SAGE, Newbury Park, CA.

Guba, Egon G. and Lincoln, Yvonna S. (1998): *Competing Paradigms in Qualitative Research*, In Ed. Lincoln, Y. S.: *The Landscape of Qualitative Research: Theories and Issues*, SAGE Publications, Thousand Oaks, California, pp. 195-220.

Gummesson, Evert (1985): *Forskare och konsult : om aktionsforskning och fallstudier i företagsekonomin,* Studentlitteratur, Lund, Sweden.

Gustafsson, Claes (1994): *Produktion av allvar: om det ekonomiska förnuftets metafysik,* Nerenius & Santérus, Stockholm, Sweden.

Gustafsson, Magnus (2002): *Att leverera ett kraftverk: förtroende, kontrakt och engagemang i internationell projektindustri (Doctoral thesis in Swedish),* Åbo Akademi University Press, Åbo.

Gustafsson, Magnus, Hellström, Magnus and Haikkola, Päivi (2005): *Modularisation Process - [Company X]*, unpublished report (confidential), PBI Research Institute for Project-Based Industry, Turku, Finland, p. 15.

Gustafsson, Magnus, Lindahl, Marcus, Karrbom, Tina and Lindholm, Tom (1999): *A study of the installation of [Company X] equipment in [Company Y]'s power plant projects A and B*, unpublished report (confidential), Åbo Akademi University / Research group for Project Based Industry, Turku, Finland, p. 7.

Gustafsson, Magnus and Wikström, Kim (2004): *Time to think - Managing projects through reflection*, Proceedings of the IRNOP VI, Turku, Finland, August 25-27.

Gustafsson, Magnus, Wikström, Kim and Haikkola, Päivi (2003): *[Bioenergy company] Customer Survey*, unpublished report (confidential), PBI Research Institute for Project-Based Industry, Turku, Finland, p. 25.

Günter, Bernd and Bonaccorsi, Andrea (1996): Project Marketing and Systems Selling - in Search of Frameworks and Insights, *International Business Review,* 5**,** pp. 531-537.

Hadjikhani, Amjad (1996): Project Marketing and the Management of Discontinuity, *International Business Review,* 5**,** pp. 319-336.

Hameri, Ari-Pekka and Nitter, P. (2002): Engineering data management through different breakdown structures in a large-scale project, *International Journal of Project Management,* 20**,** pp. 375-384.

Hayes, Robert and Wheelwright, Steven (1979): Link manufacturing process and product life cycles, *Harvard Business Review,* 57**,** pp. 133-140.

Hellström, Magnus (2002): *Short term operational screening - ett alternativt verktyg för projektstyrning,* unpublished Master's thesis, Åbo Akademi University, Turku, Finland.

Hellström, Magnus, Gustafsson, Magnus and Wikström, Kim (2005): *LIIKE - Liiketoimintamallit hajautettujen energiajärjestelmien toimittamiseen (TEKES - DENSY-ohjelma)*, unpublished report (confidential), Laboratory for Industrial Management, Åbo Akademi University, Turku, Finland, p. 32.

Hellström, Magnus and Westerholm, Thomas (2005): *[Yritys Y] riippuvuusanalyysi*, unpublished Power Point Presentation (confidential), PBI Research Institute for Project-Based Industry, Turku, Finland, p. 7.

Hellström, Magnus, Westerholm, Thomas and Wikström, Kim (2003): *Creation of Modular Product Solutions - Three Case Studies from the Finnish Project Industry*, Proceedings of the 2nd Interdisciplinary World Congress on Mass Customization and Personalization, Munich, Germany, October 6-8.

Hellström, Magnus and Wikström, Kim (2004): *Deliverable V-1-21 (Survey on modularity in ship-building)*, Part deliverable for larger report (Ed. Pitkänen, Mervi; unpublished), Laboratory for Industrial Management, Åbo Akademi University, Turku, Finland, p. 11.

Hellström, Magnus and Wikström, Kim (2005a): *Deliverable V-1-40 (Benchmarking survey on modularity in land-based industries)*, Part deliverable for larger report (Ed.

Pitkänen, Mervi; unpublished), Laboratory for Industrial Management, Åbo Akademi University, Turku, Finland.

Hellström, Magnus and Wikström, Kim (2005b): Project business concepts based on modularity – improved manoeuvrability through unstable structures, *International Journal of Project Management,* 23, pp. 392-397.

Henderson, Rebecca and Clark, Kim (1990): Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms, *Administrative Science Quarterly,* 35, pp. 9-30.

von Hippel, Eric (1990): Task partitioning: An innovation process variable, *Research Policy,* 19, pp. 407-418.

Hoare, Rohan and Seiler, Gerhard (2001): Building blocks for capital projects, *The McKinsey Quarterly*, pp. 56-63.

Hobday, Michael, Prencipe, Andrea and Davies, Andrew (2003a): *Introduction*, In Eds. Prencipe, A., Davies, A. and Hobday, M.: *The Business of Systems Integration*, Oxford University Press, UK, pp. 1-12.

Hobday, Mike (1998): Product complexity, innovation and industrial organisation, *Research Policy,* 26, pp. 689-710.

Hobday, Mike (2000): The project-based organisation: an ideal form for managing complex products and systems?, *Research Policy,* 29, pp. 871-893.

Hobday, Mike, Rush, Howard and Tidd, Joe (2000): Innovation in complex products and system, *Research Policy,* 29, pp. 793-804.

Holmström, Jorma (2000): *39. Varustelu*, In Ed. Räisänen, P.: *Laivatekniikka: modernin laivanrakennuksen käsikirja*, Turun ammattikorkeakoulu, Turku, Finland, pp. 39-1 - 39-23.

Horsti, Aleksi and Brännback, Malin (2004): *Back to Basics: Towards a Pragmatic IS*

Business Model Framework, Helsinki/Turku, Finland.

Hsuan, Juliana (1999): Impacts of supplier-buyer relationships on modularisation in new product development, *European Journal of Purchasing & Supply Management,* 5, pp. 197-209.

Hsuan Mikkola, Juliana (2004): *Product architecture modularity: Toward a general theory*, Proceedings of the Seattle, WA, August 1-6.

Hubka, Vladimir and Eder, Ernst (1988): *Theory of technical systems,* Springer, Berlin.

Hughes, Thomas (1983): *Networks of power: electrification in Western society, 1880-1930,* Johns Hopkins University Press, Baltimore.

Håkansson, Håkan (Ed.) (1982): *International Marketing and Purchasing of Industrial Goods - An Interaction Approach,* John Wiley, Chichester, UK.

Häkkinen, Pentti (1993): *Laivan koneistot,* Helsinki University of Technology, Espoo, Finland.

Hällgren, Markus (2004): *Mellan plan och kaos: en studie av avvikelser i projektintensiva organisationer*, Licentiate thesis, Umeå School of Business and Economics, Sweden.

Hölttä, Katja (2004): *Comparative analysis of product modularisation methods*, Proceedings of the NordDesign 2004 - Product Design in Changing Environment, Tampere, Finland,

IEA (2002): *Distributed Generation in Liberalised Electricity Markets*, The International Energy Agency, Paris, p. 128.

INCOSE (2005): www.incose.org/practice/whatissystemseng.aspx, retrieved in May 2005.

Ishii, Kosuke (1998): *Modularity: a Key Concept in Product Life-Cycle Engineering*, In Eds. Molina, A., Sanchez, J. and Kusiak, A.: *Handbook of Life Cycle Engineering: Concepts, models and technologies*, Kluwer Academic, Dordrecht, The Netherlands, pp. 511-531.

Iskanius, Päivi, Haapasalo, Harri and Alaruikka, Anna-Maija (2004): *Shifting the operational mode from mass production towards a project oriented business in the steel product industry*, Proceedings of the IRNOP VI, Turku, Finland, August 25-27.

Johanson, Jan and Mattsson, Lars-Gunnar (1987): Interorganizational relations in industrial systems: a network approach compared with the transaction cost approach, *International Studies of Management Organization,* 17**,** pp. 34-48.

Johnston, Phil and Duberly, Joanne (2000): *Understanding management research: an introduction to epistemology,* SAGE, London.

Johnston, Robert (1994): Operations: From Factory to Service Management, *International Journal of Service Industry Management,* 5**,** pp. 49-63.

Jurvelin, Kyösti (2005): Turun rautakourat hitsaavat unelmaa laivaksi, *Kauppalehti*, 4.5.2005, pp. 18-19.

Kadefors, Anna (1995): Institutions in building projects: implications for flexibility and change, *Scandinavian Journal of Management,* 11**,** pp. 395-408.

Kanerva, Markku, Arkke, Pertti, Hanhinen, Juha, Herrala, Kyösti, Huhtala, Matti, Kalske, Seppo, Lindqvist, Gustav, Luukkonen, Janne, Mikkonen, Ilkka, Nordling, Jan-Olof, Nurmi, Jari, Pöyliö, Esa, Revahl, Tage, Salama, Harri and Senvall, Kalle (1999): *The Future of Ship Design - Part 1,* MPI Group, Basingstoke, UK.

Kaplan, Robert (1998): Innovation Action Research: Creating New Management Theory and Practice, *Journal of Management Accounting Research,* 10**,** pp. 89-118.

Kasanen, Eero and Lukka, Kari (1993): The constructive approach in management accounting research, *Journal of Management Accounting Research,* 5**,** pp. 243-264.

Kaski, Timo (2002): *Product Structure Metrics as an Indicator of Demand-Supply Chain Efficiency: Case Study in the Cellular Network Industry*, Doctoral thesis, Helsinki University of Technology, Espoo, Finland.

Keegan, Anne and Turner, Rodney (2002): The Management of Innovation in Project-Based Firms, *Long Range Planning,* 35**,** pp. 367-388.

Kosonen, Heikki (1991): *The internationalization of industrial systems suppliers: a case study of the internationalization process of industrial systems suppliers with special emphasis on strategy and organization*, Doctoral Thesis, Helsinki School of Economics and Business Administration, Finland.

Kreiner, Kristian (1995): In search of relevance: project management in drifting environments, *Scandinavian Journal of Management,* 11**,** pp. 335-346.

Kuhn, Thomas (1962): *The structure of scientific revolutions,* University of Chicago Press, Chicago.

Kusiak, Andrew (Ed.) (1993): *Concurrent engineering: automation, tools, and techniques,* John Wiley, New York.

Lagerspetz, Olli (1998): *Trust: the tacit demand,* Kluwer, Dordrecht, The Netherlands.

Lampel, Joseph and Mintzberg, Henry (1996): Customizing Customization, *Sloan Management Review,* 38**,** pp. 21-30.

Langlois, Richard (2002): Modularity in technology and organization, *Journal of Economic Behavior & Organization,* 49**,** pp. 19-37.

Langlois, Richard (2003): The Vanishing Hand: The Changing Dynamics of Industrial Capitalism, *Industrial and Corporate Change,* 12**,** pp. 351-385.

Langlois, Richard and Robertson, Paul (1992): Networks and innovation in a modular system: lessons from the microcomputer and stereo component industries, *Research Policy,* 21**,** pp. 297-313.

Latour, Bruno (1987): *Science in action: how to follow scientists and engineers through society,* Harvard University Press, Cambridge, MA.

Latour, Bruno (1996): *Aramis or the love of technology,* Harvard University Press, Cambridge, MA.

Laufer, Alexander, Denker, Gordon and Shenhar, Aaron (1996): Simultaneous management: The key to excellence in capital projects, *International Journal of Project Management,* 14**,** pp. 189-199.

Lee, Hau (1996): Effective inventory and service management through product and process redesign, *Operations Research,* 44**,** pp. 151-159.

Levander, Kai and Sillanpää, Kari (2000): *18. Matkustaja alukset*, In Ed. Räisänen, P.: *Laivatekniikka: modernin laivanrakennuksen käsikirja,* Turun ammattikorkeakoulu, Turku, Finland, pp. 18-1 - 18-34.

Lewin, Kurt (1946): Action research and minority problems, *Journal of Social Issues,* 2**,** pp. 34-36.

Lincoln, Yvonna and Guba, Egon (1985): *Naturalistic Inquiry,* SAGE, Beverly Hills, CA.

Lind, Jan-Inge and Rhenman, Eric (1989): The SIAR School of Strategic Management, *Scandinavian Journal of Management,* 5**,** pp. 167-176.

Lindahl, Marcus (2001): *Working words - A notion on the Connection between Words, Work and Physical Entities*, Proceedings of the 4th International Conference on: Organizational Discourse, London, July 26-28.

Lindahl, Marcus (2003): *Produktion till varje pris: om planering och improvisation i anläggningsprojekt (Doctoral thesis in Swedish),* Arvinius Förlag, Stockholm, Sweden.

Linden, H. (1997): Operational, Technological and Economic Drivers for Convergence of the Electric Power and Gas Industries, *The Electricity Journal,* 10**,** pp. 14-25.

Lindholm, Jonas (2004): *Framtida leveranskoncept för små kraftverk*, unpublished Master's thesis, Åbo Akademi University, Turku, Finland.

Lindkvist, Lars (2001): *Det projektbaserade företaget - om styrning i ett distribuerat kunskapssystem*, In Eds. Berggren, C. and Lindkvist, L.: *Projekt - Organisation för målorientering och lärande*, Studentlitteratur, Lund, Sweden, pp. 258-291.

Lundin, Rolf and Söderholm, Anders (1995): A theory of the temporary organization, *Scandinavian Journal of Management,* 11**,** pp. 437-455.

Magnusson, Thomas, Tell, Fredrik and Watson, Jim (2005): From CoPS to mass production? Capabilities and innovation in power generation equipment manufacturing, *Industrial & Corporate Change,* 14**,** pp. 1-26.

Maheswari, Uma and Varghese, Koshy (2004): Project Scheduling using Dependency Structure Matrix, *International Journal of Project Management,* forthcoming**,** pp 223-230.

Mandják, T. and Veres, Z. (1998): *The D-U-C Model and the Stages of the Project Marketing Process*, Proceedings of the Fourteenth IMP Annual Conference Proceedings, Turku, Finland,

March, James (1991): Exploration and exploitation in organizational learning, *Organization Science,* 2**,** pp. 71-87.

Marx, Roberto, Zilbovicius, Mauro and Salerno, Mario Sergio (1997): The modular consortium in a new VW truck plant in Brazil: new forms of assembler and supplier relationship, *Integrated Manufacturing Systems,* 8**,** pp. 292-298.

Mattsson, Lars-Gunnar (1973): Systems selling as a strategy on industrial markets, *Industrial Marketing Management,* 3**,** pp. 107-120.

Maylor, Harvey (2001): Beyond the Gantt Chart: Project Management Moving on, *European Management Journal,* 19**,** pp. 92-100.

McCord, Kent and Eppinger, Steven (1993): *Managing the integration problem in concurrent engineering,* Working paper, Cambridge, MA.

MCPC (2003): *Proceedings of the MCPC'03 (CD-ROM)*, Proceedings of the 2nd Interdisciplinary World Congress on Mass Customization and Personalization (MCPC'03), Munich, Germany, October 6-8.

Meklin, Jukka, Lahti, Mika, Kovanen, Vesa, Arenius, Marko and Artto, Karlos (1999): *FIT-PRO - a product-oriented approach to industrial project management,* Project Management Association (PMA Finland), Helsinki.

Mercer, Glenn (1995): *Modular Supply in the 1990s: the Keys to Success (McKinsey & Co. report)*, In Ed. Unit, E. I.: *Europe's Automotive Components Business, 2nd Quarter 1995*, pp. 112-135.

Meredith, Jack (1998): Building operations management theory through case and field research, *Journal of Operations Management,* 16, pp. 441-454.

Merriam Webster Online (2004): www.m-w.com/cgibin/dictionary?book=Dictionary &va=module&x=15&y=7, retrieved 8.4.2004.

Merriam Webster Online (2005): www.m-w.com/cgi-bin/dictionary?book=Dictionary &va=standard, retrieved 20.7.2005.

Meyer, Marc and Lehnerd, Alvin (1997): *The Power of Product Platforms,* The Free Press, New York.

Meyer, Marc and Utterback, James (1993): The Product Family and the Dynamics of Core Capability, *Sloan Management Review,* 34, pp. 29-47.

Midler, Christophe (1995): "Projectification" of the firm: the Renault case, *Scandinavian Journal of Management,* 11, pp. 363-375.

Miller, Roger, Hobday, Mike, Leroux-Demers, Thierry and Olleros, Xavier (1995): Innovation in Complex Systems Industries: the Case of Flight Simulation, *Industrial & Corporate Change,* 4, pp. 363-400.

Miller, Thomas D. and Elgård, Per (1998): *Defining modules, modularity and modularisation*, Proceedings of the 13th IPS Research Seminar, Fuglsoe, Denmark.

Molina, Arturo, Sanchez, José and Kusiak, Andrew (Eds.) (1998): *Handbook of life cycle engineering: concepts, models, and technologies,* Kluwer Academic, Dordrecht, The Netherlands.

Monteverde, Kirk and Teece, David (1982): Supplier switching costs and vertical integration in the automobile industry, *Bell Journal of Economics,* 13, pp. 206-213.

Muffatto, Moreno and Roveda, Marco (2000): Developing product platforms: analysis of the development process, *Technovation,* 20, pp. 617-630.

Nilsson, Benjamin, Blomquist, Björn and Wikström, Kim (1999): Through Standard Paper Mill Concepts with Intelligent Modules to Shorter Project Times, *Projektitoiminta,* 1999, pp. 12-14.

Normann, Richard (1975): *Skapande företagsledning,* Aldus, Stockholm, Sweden.

Normann, Richard (1977): *Management for growth,* John Wiley, Chichester, UK.

Normann, Richard (1983): *Service management : ledning och strategi i tjänsteproduktion,* Liber Förlag, Malmö, Sweden.

Normann, Richard (1984): *Service management: strategy and leadership in service businesses,* John Wiley, Chichester, UK.

Normann, Richard and Ramirez, Rafael (1993): From value chain to value constellation: Designing interactive strategy, *Harvard Business Review,* 71, pp. 65-77.

Novak, Sharon and Eppinger, Steven (2001): Sourcing By Design: Product Complexity and the Supply Chain, *Management Science,* 47, pp. 189-204.

Ojanperä, Kari (2004): Autotehtaat tiukentavat otetta tuotannosta, *Tekniikka & Talous,* 7.10.2004.

Oosterman, Bas (2001): *Improving Product Development Projects by Matching Product Architecture and Organization*, Doctoral thesis, University of Groningen, The Netherlands.

Orton, Douglas and Weick, Karl (1990): Loosely Coupled Systems: A Reconceptualization, *Academy of Management Review,* 15, pp. 203-223.

Packendorff, Johann (1995): Inquiring into the temporary organization: New directions for project management research, *Scandinavian Journal of Management,* 11, pp. 319-333.

Pahl, Gerhard and Beitz, Wolfgang (1996): *Engineering design: a systematic approach,* Springer, London, UK.

Parnas, David (1972): On the criteria to be used in decomposing systems into modules, *Communications of the ACM,* 15, pp. 1053-1058.

Pavitt, Keith (2003): *Specialization and Systems Integration - Where Manufacture and Services Still Meet*, In Eds. Prencipe, A., Davies, A. and Hobday, M.: *The Business of Systems Integration*, Oxford University Press, UK, pp. 78-91.

Pettigrew, Andrew (1990): Longitudinal Field Research on Change: Theory and Practice, *Organization Science,* 1, pp. 267-292.

Pettigrew, Andrew (1997): What is processual analysis?, *Scandinavian Journal of Management,* 13, pp. 337-348.

Piller, Frank and Meier, Roland (2001): Strategien zur effizienten Individualisierung von Dienstleistungen - Ansätze von Mass Customization im Dienstleistungsbereich, *Industrie-Management,* 17, pp. 13-17.

Piller, Frank and Möslein, Kathrin (2002): *Economies of interaction and economies of relationship: value drivers in a customer centric economy*, Proceedings of the Paper accepted for the ANZAM-IFSAM 2002 Conference, Brisbane, Australia, July 2002.

Piller, Frank and Reichwald, Ralf (2002): *Mass Customization*, In Eds. Li, Z. and Possel-Doelken, F.: *Strategic Production Networks*, Springer, New York, pp. 389-421.

Piller, Frank and Waringer, Daniela (1999): *Modularisierung in der Automobilindustrie - Neue Formen und Prinzipen: Modular Sourcing, Plattformkonzept und Fertigungssegmentierung als Mittel des Komplexitätsmanagements,* Shaker, Aachen, Germany.

Pimmler, Thomas and Eppinger, Steven (1994): *Integration analysis of product decompositions*, Proceedings of the ASME Design Theory and Methodology Conference, Minneapolis, MN.

Pine, B. Joseph, Victor, Bart and Boynton, Andrew C. (1993): Making mass customization work, *Harvard Business Review,* 71, pp. 108-116.

Pine, Joseph (1992): *Mass Customization: The New Frontier in Business Competition,* Harvard Business School Press, Boston, MA.

Pine, Joseph, Peppers, Don and Rogers, Martha (1995): Do you want to keep your customers forever?, *Harvard Business Review,* 72, pp. 103-114.

PMI Standards Committee (2000): *A guide to the project management body of knowledge: (PMBOK guide),* Project Management Institute, Newton Square, Pa.

Popper, Karl (1935): *Logik der Forschung (The Logic of Scientific Discovery),* Julius Springer, Vienna, Austria.

Popper, Karl (1996): *En värld av benägenheter (A world of propensities),* Symposion, Stockholm, Sweden.

Porter, Michael (1985): *Competitive advantage: creating and sustaining superior performance,* The Free Press, New York.

Porter, Michael (1996): What Is Strategy?, *Harvard Business Review,* 74**,** pp. 61-78.

Prahalad, C. K. and Hamel, Gary (1990): The Core Competence of the Corporation, *Harvard Business Review,* 68**,** pp. 79-91.

Prencipe, Andrea (1997): Technological competencies and product's evolutionary dynamics a case study from the aero-engine industry, *Research Policy,* 25**,** pp. 1261-1276.

Prencipe, Andrea (2000): Breadth and depth of technological capabilities in CoPS: the case of the aircraft engine control system, *Research Policy,* 29**,** pp. 895-911.

Prencipe, Andrea, Davies, Andrew and Hobday, Michael (Eds.) (2003): *The Business of Systems Integration,* Oxford University Press, UK.

Project Management Institute (2001): *Project Management Institute practice standard for work breakdown structures,* Project Management Institute, Newtown Square, Pa.

Putnam, Hilary (1990): *Realism with a human face,* Harvard University Press, Cambridge, MA.

Quinn, James, Doorley, Thomas and Paquette, Penny (1990): Beyond Products: Services-Based Strategy, *Harvard Business Review,* 68**,** pp. 58-67.

Rhenman, Eric (1970): *Företaget och dess omvärld: organisationsteori för långtidsplanering,* Bonniers, Stockholm, Sweden.

Riitahuhta, Asko and Pulkkinen, Antti (Eds.) (2001): *Design for Configuration - A Debate based on the 5th WDK Workshop on Product Structuring,* Springer, Berlin.

Robertson, David and Ulrich, Karl (1998): Planning for Product Platforms, *Sloan Management Review,* 39**,** pp. 19-31.

Roegner, Eric, Seifert, Torsten and Swinford, Dennis (2001): Puttinga price on solutions, *The McKinsey Quarterly***,** pp. 98-103.

Rogoll, Timm and Piller, Frank (2003): *Marktsudie 2003: Konfigurationssysteme für Mass Customization und Variantenproduktion: Strategie, Erfolgsfaktoren und Technologie von Systemen zur Kundenintegration,* Think Consult, Munich, Germany.

Rotkirch, Carl-Gustaf (2000): *40. Alihankinta ja ostot*, In Ed. Räisänen, P.: *Laivatekniikka: modernin laivanrakennuksen käsikirja*, Turun ammattikorkeakoulu, Turku, Finland, pp. 40-1 - 40-18.

Routio, Pentti (1995): www2.uiah.fi/projects/metodi/110.htm, retrieved in April 2004.

Rutenberg, D.P. (1971): Design Commonality to Reduce Multi-Item Inventory - Optimal Depth of a Product Line, *Operations Research,* 19, pp. 491-509.

Sako, Mari (1991): The role of “Trust” in Japanese buyer–supplier relationships, *Ricerche Economiche,* 45, pp. 449–474.

Sako, Mari (2003): *Modularity and Outsourcing: The Nature of Co-evolution of Product Architecture and Organization Architecture in the Global Automotive Industry*, In Eds. Prencipe, A., Davies, A. and Hobday, M.: *The Business of Systems Integration*, Oxford University Press, UK, pp. 229-253.

Sanchez, Ron (1995): Strategic flexibility in product competition, *Strategic Management Journal,* 16, pp. 135-159.

Sanchez, Ron (1997): Strategic Management at the Point of Inflection: Systems, Complexity and Competence Theory, *Long Range Planning,* 30, pp. 939-946.

Sanchez, Ron (1999): Modular Architectures in the Marketing Process, *Journal of Marketing,* 63, pp. 92-111.

Sanchez, Ron (2003): *Commentary (on "Modularity, flexibility, and knowledge management in product and organization design"),* In Eds. Garud, R., Kumaraswamy, A. and Langlois, R. N.: *Managing in the modular age: architectures, networks, and organizations*, Blackwell, Malden, MA, pp. 380-389.

Sanchez, Ron and Collins, Robert P. (2001): Competing - and Learning - in Modular Markets, *Long Range Planning,* 34, pp. 645-667.

Sanchez, Ron and Mahoney, Joseph (1996): Modularity, flexibility, and knowledge management in product and organization design, *Strategic Management Journal,* 17, pp. 63-76.

Sanderson, Susan and Uzumeri, Mustafa (1995): Managing product families: The case of the Sony Walkman, *Research Policy,* 24, pp. 761-782.

Schein, Edgar (1995): Process consultation, action research and clinical inquiry: are they the same?, *Journal of Managerial Psychology,* 10, pp. 14-19.

Schilling, Melissa (2000): Toward a General Modular Systems Theory and Its Application to Interfirm Product Modularity, *Academy of Management Review,* 25, pp. 312-334.

Schilling, Melissa and Steensma, Kevin (2001): The use of modular organizational forms: an industry-level analysis, *Academy of Management Journal,* 44, pp. 1149-1168.

Schimmoller, Brian (1998): Power Plants Go Modular, *Power engineering,* 1998, pp. 14-19.

Schön, Donald (1983): *The Reflective Practitioner - How professionals think in action,* Temple Smith, London.

Scudder, Gary and Hill, Craig (1998): A review and classification of empirical research in operations management, *Journal of Operations Management,* 16, pp. 91-101.

Sievänen, Matti (2004): *The Effects of Customization on Capital Goods Manufacturing Business*, Doctoral thesis, Tampere University of Technology, Finland.

Silverman, David (1997): *Qualitative research: theory, method and practice,* SAGE, London.

Simon, Herbert (1962): The Architecture of Complexity, *Proceedings of the American Philosophical Society,* 6, pp. 467-482.

Simon, Herbert (2003): *The Architecture of Complexity (Reprint)*, In Eds. Garud, R., Kumaraswamy, A. and Langlois, R.: *Managing in the modular age: architectures, networks, and organizations*, Blackwell, Malden, MA, pp. 15-37.

Skaates, Maria and Tikkanen, Henrikki (2003): International project marketing: an introduction to the INPM approach, *International Journal of Project Management,* 21, pp. 503-510.

Sosa, Manuel, Eppinger, Steven and Rowles, Craig (2003): Identifying Modular and Integrative Systems and Their Impact on Design Team Interactions, *Journal of Mechanical Design,* 125, pp. 240-242.

Sosa, Manuel, Eppinger, Steven and Rowles, Craig (2004): The Misalignment of Product Architecture and Organizational Structure in Complex Product Development, *Management Science,* 50, pp. 1674-1689.

Starr, Martin (1965): Modular Production - A New Concept, *Harvard Business Review,* 43, pp. 131-142.

Steward, Donald (1981): The Design Structure System: A Method for Managing the Design of Complex Systems, *IEEE Transactions on Engineering Management,* EM-28, pp. 71-74.

Stone, Robert (2000): A heuristic method for identifying modules for product architectures, *Design Studies,* 21, pp. 5–31.

Storholm, Stefan and Wikström, Kim (1995): Simultaneous Project Care - A Way to Successful project Execution, *Project Management,* 1995, pp. 12-15.

Suh, Nam (1998): Axiomatic design theory for systems, *Research in Engineering Design-Theory Applications and Concurrent Engineering,* 10, pp. 189-209.

Sundgren, Niklas (1999): Introducing Interface Management in New Product Family Development, *Journal of Product Innovation Management,* 16, pp. 40-51.

Susman, Gerald and Evered, Roger (1978): An Assessment of the Scientific Merits of Action Research, *Administrative Science Quarterly,* 23, pp. 582-603.

Söderlund, Jonas (2004): On the broadening scope of the research on projects: a review and a model for analysis, *International Journal of Project Management,* 22, pp. 655-667.

Söderlund, Jonas (2005): *Projektledning & projektkompetens - Perspektiv på konkurrenskraft,* Liber, Malmö, Sweden.

Taiminen, Pekka (2000): *30. Telakkatekniikan perusteet*, In Ed. Räisänen, P.: *Laivatekniikka: modernin laivanrakennuksen käsikirja*, Turun ammattikorkeakoulu, Turku, Finland, pp. 30-1 - 30-17.

Takeishi, Akira and Fujimoto, Takahiro (2003): *Modularization in the Car Industry: Interlinked Multiple Hierarchies of Product, Production, and Supplier Systems*, In Eds. Prencipe, A., Davies, A. and Hobday, M.: *The Business of Systems Integration*, Oxford University Press, UK, pp. 229-253.

Tell, Fredrik (2003): *Integrating Electrical Power Systems: From Individual to Organizational Capabilities*, In Eds. Prencipe, A., Davies, A. and Hobday, M.: *The Business of Systems Integration*, Oxford University Press, UK, pp. 56-77.

The Columbia Encyclopedia (2004): www.bartleby.com/65/mo/module.html, retrieved 8.4.2004.

Thompson, James (1967): *Organizations in action; social science bases of administrative theory,* McGraw-Hill, New York.

Tikkanen, Henrikki (1997): *A network approach to industrial business processes: a theoretical and empirical analysis*, Doctoral thesis, Turku school of economics and business administration, Turku, Finland.

Toivonen, Jouko (2000): *Reppumiehistä kokonaistoimituksiin: telakkateollisuuden alihankinnan toimintatapamuutoksen institutionaalinen analyysi*, Doctoral thesis, Turun kauppakorkeakoulu, Finland.

Toulmin, Stephen (2001): *Return to Reason,* Harvard University Press, Cambridge, MA.

Turkki, Kirsi (1997): EU vaatii lisää kilpailukykyä tuetuilta telakoilta, *Turun Sanomat*, 10.9.1997, Turku, Finland.

Turner, Rodney (1992): *The handbook of project-based management: improving the processes for achieving strategic objectives,* McGraw-Hill Book, London.

Turner, Rodney (2000): Do you manage work, deliverables or resources? (Editorial), *International Journal of Project Management,* 18, pp. 83-84.

Tushman, Michael and Anderson, Philip (1986): Technological Discontinuities and Organizational Environments, *Administrative Science Quarterly,* 31, pp. 439-465.

Tushman, Michael and Murmann, Johann (1998): Dominant designs, technology cycles, and organizational outcomes, *Research in Organizational Behavior,* 20, pp. 232-266.

Tushman, Michael and Murmann, Johann (2003): *Dominant designs, technology cycles, and organizational outcomes (Reprint)*, In Eds. Garud, R., Kumaraswamy, A. and Langlois, R.: *Managing in the modular age: architectures, networks, and organizations*, Blackwell, Malden, MA, pp. 316-347.

Ulrich, Karl (1995): The role of product architecture in the manufacturing firm, *Research Policy,* 24, pp. 419-440.

Ulrich, Karl (2003): *Commentary (on "The role of product architecture in the manufacturing firm")*, In Eds. Garud, R., Kumaraswamy, A. and Langlois, R. N.: *Managing in the* *modular age: architectures, networks, and organizations*, Blackwell, Malden, MA, pp. 146-148.

Ulrich, Karl and Eppinger, Steven (1995): *Product design and development,* McGraw-Hill, New York.

Ulrich, Karl and Seering, Warren (1990): Function sharing in mechanical design, *Design Studies,* 11, pp. 223-234.

Ulrich, Karl and Tung, Karen (1991): *Fundamentals of product modularity*, Cambridge, MA.

Utterback, James and Abernathy, William (1975): Dynamic Model of Process and Product Innovation, *Omega-International Journal of Management Science,* 3, pp. 639-656.

Uzumeri, Mustafa and Sanderson, Susan (1995): A framework for model and product family competition, *Research Policy,* 24, pp. 583-607.

Voss, Chris, Tsikriktsis, Nikos and Frohlich, Mark (2002): Case research in operations management, *International Journal of Operations & Production Management,* 22, pp. 195-219.

Walker, Gordon and Weber, David (1984): A Transaction Cost Approach to Make-or-Buy Decisions, *Administrative Science Quarterly,* 29, pp. 373.

Wang, Q. and von Tunzelmann, Nick (2000): Complexity and the functions of the firm: breadth and depth, *Research Policy,* 29, pp. 805-818.

Westbrook, Roy (1995): Action research: a new paradigm for research in production and operations management, *International Journal of Operations & Production Management,* 15, pp. 6-20.

Westerman, George and Tushman, Michael (2003): *Commentary (on "Dominant designs, technology cycles, and organizational outcomes")*, In Eds. Garud, R., Kumaraswamy, A. and Langlois, R. N.: *Managing in the modular age: architectures, networks, and organizations*, Blackwell, Malden, MA, pp. 348-361.

Wijnolst, Niko and Wergeland, Tor (1996/1997): *Shipping,* Delft University Press, The Netherlands.

Wikström, Kim (2000): *Det aldrig återupprepades teori: tankar och idéer om industriella projekt (Doctoral thesis in Swedish),* Åbo Akademi University Press, Finland.

Wikström, Kim (2004): *The situation changes the possibilities - the starting point for project activities (Inaugural address),* Inaugural address for Professorship, Industrial Management, Reports, Finland.

Wikström, Kim (2005): Personal communication, March 2005.

Wikström, Kim and Gustafsson, Claes (1999): Ett skapande KAOS, *Projektitoiminta,* 1999, pp. 24-25.

Wikström, Kim, Hellström, Magnus and Westerholm, Thomas (2005): *Dependency Analysis of the Engine Room (Final report)*, unpublished Power Point Presentation (confidential), PBI Research Institute for Project-Based Industry, Turku, Finland, p. 30.

Wikström, Kim and Storholm, Stefan (1999): Industrial Lego® with Intelligence, *Projektitoiminta,* 1999, pp. 7-9.

Wikström, Kim, Westerholm, Thomas and Toivola, Pia (2004): *Teknisen informaation tuottaminen ja hallinta tulevaisuuden laivaprojekteissa - Uusi toimintatapa*, MERIKE / PBI Research Institute for Project-Based Industry, Turku, Finland, p 34.

Winch, Peter (1958): *The idea of a social science and its relation to philosophy,* Routledge & Kegan Paul, London.

Wise, Richard and Baumgartner, Peter (1999): Go Downstream: The New Profit Imperative in Manufacturing, *Harvard Business Review,* 77, pp. 133-141.

Wittgenstein, Ludwig (1953): *Philosophical investigations,* Blackwell, Oxford.

Woodward, Joan (1958): *Management and Technology,* Her Majesty's Stationary Office, London.

von Wright, Georg (1971): *Explanation and Understanding,* Routledge & Kegan Paul, London.

Youker, Robert (1992): Managing the international project environment, *International Journal of Project Management,* 10, pp. 219-226.

Zhang, Lihong (2004): *Managing the specification process in complex product and systems projects*, Doctoral Thesis, University of Brighton, Brighton, UK.

APPENDIX 1: THE EMPRICAL DATA SOURCES

The main empirical data sources for this study are (presented in Table 3-a. in the thesis):

- participant observation-studies in two international power plant projects (1.)
- a customer survey for a company in the decentralised energy systems industry [company X] (E-3.)
- participation in a technology programme on distributed energy systems (DENSY) (E-2.)
- participation in an industry programme among EU shipbuilders (Intership) (S-2.)
- the findings from a technology programme in the Finnish marine cluster (MERIKE) (S-3.)
- four DSM-based studies in the ship-building industry (S-4-7)
- a DSM-based study in the decentralised energy systems industry [company X] (E-4.).

(E-3.), (E-4.) and (S-4.-7.) have already been discussed to required extent in the thesis itself. Below I will present (1.), (E-2.), (S-2.) and (S-3.) in some more detail.

1. Practical experience from power plant projects (1.)

My almost two year long working experience from the power systems industry includes a seven month trainee period in 2000 and 2001 on a construction site in India (for more information, see Hellström, 2002) and later on in 2002 a one year employment for another power project, including nine month stay on a similar building site in Brazil. Both projects belonged to the above 100 MW size range. In the former project I was able to make observations from the start of the mechanical and electrical installation works until the commissioning of the plant. In the latter I practically participated from contract signing until handing over of the plant to the customer, thus in addition to my previous experience in India getting a grasp of other phases such as design, procurement, shipping, transportation, site mobilisation (including sub-contracting) and civil works. The empirical data from these periods include field diaries, photos and project documentation, such as contracts, correspondence, monthly reports, time schedules, organization charts and plans.

2. The DENSY case study (E-2.)

In 2003 Tekes[1] launched a national technology programme for distributed energy systems (DENSY[2]). The overall objective of the programme is to assist Finnish industry in developing products and services for the global market.

Within the DENSY-programme I participated in a research group that together with a company consortium consisting of two equipment suppliers, one engineering firm, one systems integrator, one construction firms and one operator (energy company) set out to explore new business concepts for the delivery and operation of decentralized energy solutions (see Figure 3-3). Basically, the objectives of this project were:

1) To create a product-service palette for the consortium.
2) To develop a process for modularisation according to functionality.
3) To outline the procedure for creating and maintaining a business network.
4) To create a new project management process, for the planning and controlling of a modularised project.

The data-collection was made in four phases. First, introductory interviews among the involved parties regarding problems and obstacles in their current way of working were made. Nine thematic interviews were conducted and recorded, each 1-2 hours long. The ideas and thoughts from the interviews were categorised and brought up for discussion on a consortium meeting.

Second, following Latour's (1987) idea of studying science in the making or in other words, like the title of his book, *Science in Action*, real-time studies of some three 'pilot projects' within the distributed energy market were carried out. For the purpose of data collection a student working on his master's thesis was assigned two make participant observation on these projects at the systems integrators office. His task was to document interaction between different systems and tasks in the projects. His findings were continuously reviewed and refined for presentation at consortium meetings.

Third, a second round of interviews was conducted among the consortium members regarding the willingness to share a larger scope of the projects. To cover the market some additional suppliers to the systems integrator were included in the

---

[1] The Finnish National Technology Agency.

[2] http://akseli.tekes.fi/Resource.phx/enyr/densy/index.htx

‘sample’. Eight interviews with the specific aim to map each firm’s potential scope of supply on a product-service palette were conducted. Again, the results were discussed among the consortium members.

Fourth, to cover the project management dimension another student was assigned to assist some project managers at the systems integrator’s office. His task was to look at the information flow in the project from the project manager’s point-of-view. Otherwise this participant observation study was similar to the other one detailed earlier.

Finally, an on-going dialogue with suppliers, sub-suppliers, operators and other players in the field characterised the work in the DENSY-project.

3. International research programme on ship building (S-2.)

Intership[1] is an EU-directed and -financed applied research programme with the ultimate aim to increase the competitiveness of EU shipbuilders. The focus is on complex one-of-a-kind vessels. The programme also aims to improve vertical integration within the maritime communities and horizontal cooperation between the EU shipyards. More officially, the following main objectives are set (Intership 2005):

- *Increasing significantly the competitiveness of […] cruise and ferry shipbuilders…*
- *Development of better products, considering the entire life cycle of complex ships…*
- *Drastical* (sic) *reduction of building and development cost as well as time-to-market of innovative solutions…*

The programme covers a whole range of aspects so that the entire European maritime community is expected to benefit from it. One particular area considered is modularisation. Within that sub-project I have participated in and/or with the following studies:

A) A community wide analysis of the affecting factors and success criteria for a modular ship concept. In this project my task was to perform an extensive literature review of modularity and reflect upon the implications of it for project-based industries such as ship building. I was able to take part of the results of this project through the final report, meetings, work shops and discussions with the other participants.

B) A survey on attitudes, ideas and best practices regarding modularisation among EU ship builders. Based on the literature review in the A-project a questionnaire covering some general aspects of modularity was constructed. The aim was not to find causal relationships but to get a landscape view of the current status of modularisation among the European ship yards. The questionnaire was

---

[1] www.intership-ip.com/partners.phtml

sent to seven yards. The idea was that three persons representing different organisational units (strategic management, operations and development) from each yard would answer the questionnaire. 14 filled questionnaires were received, thus yielding a 67% response rate. The respondents were almost equally distributed over the three organisational categories. The sample is indeed too small for far reaching statistical generalizations, not the least between the organisational categories, but the results certainly give an indication of the current state of modularity in ship building.

C) A benchmarking study of attitudes, ideas and best practices regarding modularisation between EU ship builders and companies delivering land-based capital goods. The same questionnaire as in the B-study was used with same slight modifications. Again three organisational categories were aimed at, this time in 27 different companies. Through the 22 persons from 12 different companies who filled the questionnaire a response rate of some 27% was achieved. The purpose of this study was to compare the current practices in ship building with those of the suppliers of land-based capital goods, which presumably exhibit a higher degree of modularity due to higher production volumes.

D) A study on the state-of-the-art practices and the current way of working regarding modular solutions in the machinery space (engine room) of ships. This study was part of a larger project with the specific aim to develop concepts and design solutions for modular machinery and equipment. The study would serve to describe the status, trends and potential for further modularisation of the machinery space. The study explored the visions and thoughts of the managerial construction personnel through eight interviews on the Turku ship yard. The interviews were conducted by two colleagues in the research group that I belong to. The interviews were analysed using qualitative means and the results were summarised in a report for the Intership consortium. The report also included a comparison with land-based power plants and a short analysis of the offerings of the main engine suppliers. I have had the possibility to take part of the overall results of the larger project through works shops and meetings arranged during the project.

The data from the Intership programme clearly feeds Q1). Some material might also be of relevance for the first (organisational) part of Q2).

4. National research programme on the marine industry (S-3.)

In Finnish, from the programme website:

> *MERIKE on toimialakohtainen teknologiaohjelma, jonka tavoitteena on valmistaa suomalaista meriteollisuutta toimintalogiikan muutokseen, joka tarvitaan alan liiketoiminnan volyymin ja kannattavuuden säilyttämiseksi ja kasvattamiseksi.*[1]

In Finnish, from the sub-project website:

> *Meriteollisuudessa suuntaus on yhä funktionaalisempiin ratkaisuihin, joiden perusarkkitehtuuri on yksinkertainen ja sallii muunneltavuutta elinkaaren aikana. Hyödynnettävät keinot ovat mm. informaatioteknologian tuomat mahdollisuudet, tuotteen ja palvelun modularisointi sekä toteutus ja innovatiivisuus jotka perustuvat erityyppisiin verkottumismalleihin. Nämä muutokset heijastuvat teknisen informaation tuottamiseen ja hallintaan monessa suhteessa. Hankkeen tavoitteena on luoda viitekehys siihen miten tekninen informaatio tuotetaan ja miten sitä hallitaan meriteknisessä ympäristössä sekä luoda kilpailukykyisiä menettelytapoja ja standardeja/vakiointeja meriteknisen tulevaisuuden tuotteen määrittelyyn ja suunnitteluun sekä teknisen informaation tuottamiseen ja hallintaan.*[2]

A brief summary in English (my free translation):

> MERIKE is an industry specific technology programme, aiming at preparing the Finnish marine industry for a change in the upcoming industry/business logic. The programme emphasises functional solutions and simple architectures and adopts a life-cycle perspective. The means are in particular IT and modularisation.

---

[1] websrv2.tekes.fi/opencms/opencms/OhjelmaPortaali/Kaynnissa/MERIKE/fi/etusivu.html

[2] websrv2.tekes.fi/opencms/opencms/OhjelmaPortaali/Kaynnissa/MERIKE/fi/system/projekti.html?id=8027686&nav=Projekti

The business of large-scale industrial goods, such as luxury cruisers and power plants, is characterised by a demand for faster deliveries and reduced cost. Yet every project is faced with new circumstances and special customer needs. In addition, ever more new functions and services are wanted. The deliveries have become so demanding that many contractors find it difficult to successfully handle the growing palette of systemic goods and services. One way to cope with the increased complexity is to decompose the deliveries into modular entities. Modularisation has proved successful in high-volume sectors such as the home electronics and automotive industries. How should companies delivering low volume, complex capital goods go about when 'going modular'? This book seeks an answer to this crucial question by making use of a clinical approach where real world products and projects are studied.

Åbo Akademi University Press
ISBN 951-765-294-1
9789517 652940