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THE COST EFFECT OF EARLY PHASE ASSEMBLY UTILIZATION IN COMPLEX PROJECT PRODUCT DELIVERY

Examiners:
Professor Vesa Harmaakorpi
Post-Doctoral Researcher Satu Rinkinen

ABSTRACT

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The main purpose of this thesis was to find out the cost effects of assembly utilization in a case company context of complex project product deliveries in a capital goods industry. The research was carried out as a case study research that was based on exploration of two distinctive module assemblies by comparing their alternative building methods in a case company context.

Based on the literature review performed at the beginning of the thesis, it provides supportive examples arguing that modularity as an assembly method brings advantages in terms of costs. Furthermore, it argues that work done at early phases brings also cost savings for the case company. The study revealed that assembly utilization has positive effects in accelerating construction and assembly operations of selected case examples. Advantages occurred in reduction of lead times and thus in reduced costs in execution of such operations. However, there occurred also increased costs mainly in design activities of such assemblies which had significant effects to the overall results.

TIIVISTELMÄ

Tekijä: Oskari Miettinen

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Diplomityö. Lappeenrannan teknillinen yliopisto, tuotantotalous.
117 sivua, 41 kuvaa, 15 taulukkoa ja 11 liitettä
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Tämän työn tarkoituksena oli tutkia kokoonpanotyön hyödyntämisen kustannusvaikutuksia kohdeyrityksessä, joka valmistaa monimutkaisia projektituotteita pääomahyödykemarkkinoille. Tutkimus suoritettiin tapaustutkimuksena, joka perustui kahden erillisen moduulikokoonpanon tutkimiseen vertailemalla niiden vaihtoehtoisia rakennustapoja kohdeyrityksessä.

Tutkimuksen alussa suoritettu kirjallisuustarkastelu osoitti esimerkein, että modulaarisuutta hyödyntävä kokoonpanotyö tuottaa kustannussäästöjä. Lisäksi kirjallisuuskatsaus esitti, että kohdeyrityksen toimintaympäristössä kustannussäästöjä muodostuu rakennusprosessin mahdollisimman aikaisessa vaiheessa suoritetusta työstä. Valituille esimerkkitapauksille suoritettu tutkimus osoitti, että kokoonpanotyön hyödyntäminen tehosti positiivisella tavalla niiden rakentamis- ja kokoonpanotehtävien läpimenoaikaa, mikä pienensi myös niiden aiheuttamia kustannuksia. Kokoonpanotyön hyödyntäminen lisäsi kuitenkin myös kustannuksia etenkin niiden suunnittelun osalta, mikä heijastui merkittävällä tavalla myös tutkimuksen lopputuloksiin.

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As a result of finalizing this thesis, the time has come to complete my studies at LUT. Enormous thanks to all my friends for the fantastic time we had during these years in Lappeenranta. Finally, I want to thank my family for your encouragement and support during my studies.

Looking forward to next challenges,

Turku, 1st of December 2017

Oskari Miettinen

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LIST OF ABBREVIATIONS

ABC	Activity-Based Costing
AC	Air Conditioning
ATO	Assemble to Order
BfP	Brownfield Process
CE	Concurrent Engineering
CODP	Customer Order De-coupling Point
CoPS	Creation of Complex Products and Systems
CPM	Critical Path Method
CTO	Configure to Order
ETO	Engineering to Order
FCU	Fan Coil Unit
HVAC	Heating, Ventilation and Air Conditioning
LPD	Late-Point Differentiation
MFD	Modular Function Deployment
MTO	Make to Order
MTS	Make to Stock
OBS	Organization Breakdown Structure
OEM	Original Equipment Manufacturer
OPP	Order Penetration Point
PBS	Product Breakdown Structure
TCO	Total Cost of Ownership
TK	Turnkey
WBS	Work Breakdown Structure

1 INTRODUCTION

This Master’s Thesis has been done as a part of Industrial Management degree program at Lappeenranta University of Technology. The main purpose of the thesis was to find out the cost effects of assembly utilization in a case company context of complex project product deliveries. The case company is operating in a capital goods industry producing and delivering mainly modern cruise vessels. In the shipbuilding context of this thesis, assembly utilization is considered from the modularization point of view. Modularity has been carried out in the shipbuilding for a long time. Nevertheless, there still exists a lack of concrete and explicit examples taking a stand on its cost effects, which inspired to do this thesis. In order to be able to understand the core of the research, the first necessary steps were to explore the current literature on a project business and modularity. Furthermore, cost accounting and formation of costs have been treated briefly in relation to the research context.

1.1 Research background and goals

Modularization has evolved during the recent decades in several industries, mainly in industries of mass production. Car manufacturing might be the best known and one of the most advanced industries of utilizing modularity. These days, one emerging trend is modular buildings such as modular detached houses which can be built off-site and brought to site as appropriate prefabricated subassemblies in order to gain advantages for the building process. In a project business of capital goods industry modularity utilization has developed a bit slower due to the complex product structures and the general feature of one-of-a-kind product deliveries. One significant reason for the challenges in utilization of modularity is continuously changing product structures and thus, the lack of constant repetition between deliveries. Such features make modularity utilization necessary to be supported by the corporate management. It requires strategical decision-making and consistent daily operation in order to achieve set targets.

Despite the challenges, principles of modularity and modularization are well-known in the assembly and building operations of the ships in the case company. Just to name a few of the most common modules of traditional vessels, they consist of cabin modules, structural units, elevators and staircases. Although such modules have been used over many shipbuilding projects, there is still a lack of clear understanding about their cost effects. Several other advantages of modules usage have already been identified in the yard though. Thus, the main emphasis of this thesis is to answer for the case company's desire to clarify the cost effects affected by modularity utilization in their operating environment.

1.2 Research questions and scopes

Because the explicit purpose of this thesis is to provide an answer for the case company's desire to clarify the cost effects affected by modularity utilization in their operating environment of complex project product deliveries, the main research question can be set as follows:

"What are the cost effects of modularity utilization for the case company?"

In order to be able to answer for the main research question as well as to expand the understanding of the context of the research scope, it is essential to divide the main research question into the following sub research questions:

"Which variables determine the cost effects of modularity utilization?"

"How do those costs differ from the costs of non-modular way of working?"

"What are the main characteristics of the most idealistic modular product for the case company?"

Theoretical frameworks of this thesis have been chosen in a way they offer a sufficient comprehensive literature on mentioned topics and are suitable for the research scope and the case company context. The practical research about the cost effects of modularity utilization is limited to focus on certain case examples in order to serve the case company and its needs in the best possible way. Selected case examples cover quite small proportion of the ship as a huge product entity. However, the research and the results of selected examples offer valuable knowledge for the case company and its further purposes.

The results of this thesis are mainly useful for the case company's purposes and are not directly applicable for the general use in different contexts, although they might show some guidelines for other purposes as well. Access to some data used in this study is deliberately limited due to the sensitive nature of the material. Undisclosed and confidential material is located in the appendixes hold by the case company.

1.3 Research methods

This thesis follows the structure of a case study research method. Robson (2011, p. 136) defines case study as *"a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence"*. Robson (2011, p. 136) highlights case study's main characteristic to be the focus on a particular case or couple of different cases in their real-life context. Hirsijärvi et al. (2015, p. 135) and Järvinen (2004, p. 74) emphasize also to utilize several methods in data gathering such as inquiries, interviews, observations and archived materials to get better understanding and wider scope covered about regarding on the case under review. According to Robson (2011, p. 136) both qualitative and quantitative data collection methods are typically used in case study researches, and thus he calls it also as a flexible design (Robson 2011, p. 131). Furthermore, Hirsijärvi et al.

(135-137) emphasize also to use both methods simultaneously mutually supportive although they are often seen as opposite and mutually exclusive ones.

The literature review of this thesis is based on scientific publications, articles and researches from databases along with published books from the chosen literature areas to create appropriate theoretical frameworks behind the study as well as to create understanding about the context and the core of the research scope. The latter, the empirical part of the thesis is focused on two separate case studies and combines features of qualitative and quantitative methods in gathering and processing the data during the research. The main data collection methods include several ways and sources in a way comprehensive understanding of case studies were gathered and capabilities to answer research questions were achieved. They consist of empirical observations done at case company's production stages, unstructured interviews and discussions with several case company's experts as well as available data gathered from case company's IT-systems. Unstructured interviews and discussions were especially used to get familiar with case company's processes at the beginning of the research because the environment was totally new for the author. A big share of the exploited knowledge seemed to be tacit that revealed after those conversations.

According to Hirsijärvi et al. (2015, p. 158) hypothesis is an anticipated solution or an explanation for the research problem which can be set for a quantitative research that is a kind of explanatory and comparative research. This thesis has mentioned both the characteristics and the hypothesis for the main research question can be set as follows:

Modularity utilization creates cost savings in complex project product deliveries.

Arguments that support the set hypothesis can be found in literature and will be discussed in the theory part of the thesis. The following research will testify whether the hypothesis is correct or not in the context of case company and within the selected module case examples.

1.4 Structure of the thesis

This chapter provides a description of the structure of the thesis. The figure 1 below gives a brief summary of the structure. As can be seen from the figure, the thesis includes seven main chapters and each of them consists of inputs and outputs data which are also set in the figure. The thesis can roughly be divided into two parts: the first part consists of three theoretical chapters (2-4) and the latter empirical part consists also of three chapters (5-7) which consider the selected module case examples.

Chapter one discusses backgrounds, motives and goals of the study. It sets research questions, limitations and hypothesis for the study as well as presents the used research methods and provides a short presentation of the case company at the end of the chapter. Chapter two starts the theoretical part of the thesis and concentrates on the subject of project business. It defines the concept and provides an overview of its typical characteristics as well as introduces essential tools for project planning and management. The following third chapter concentrates on the multidimensional concept of modularity. It defines the most relevant concepts and presents types of modularity, principles of modular product design as well as focuses on the task management within modularity. The fourth chapter familiarizes the reader with cost categories, cost accounting and cost formation in manufacturing firm.

Chapter five starts the empirical part of the thesis. Initially, it describes case company’s processes in more details, introduces the research scope and presents the research processes about the cost effects of two different module case examples. Chapter six summarizes the research of case studies by discussing results and findings and answers for the research questions. Chapter seven concludes the thesis by discussing theoretical implications and managerial recommendations. It provides also guidelines for suggested future research objectives before the list of used references at the end of the thesis.

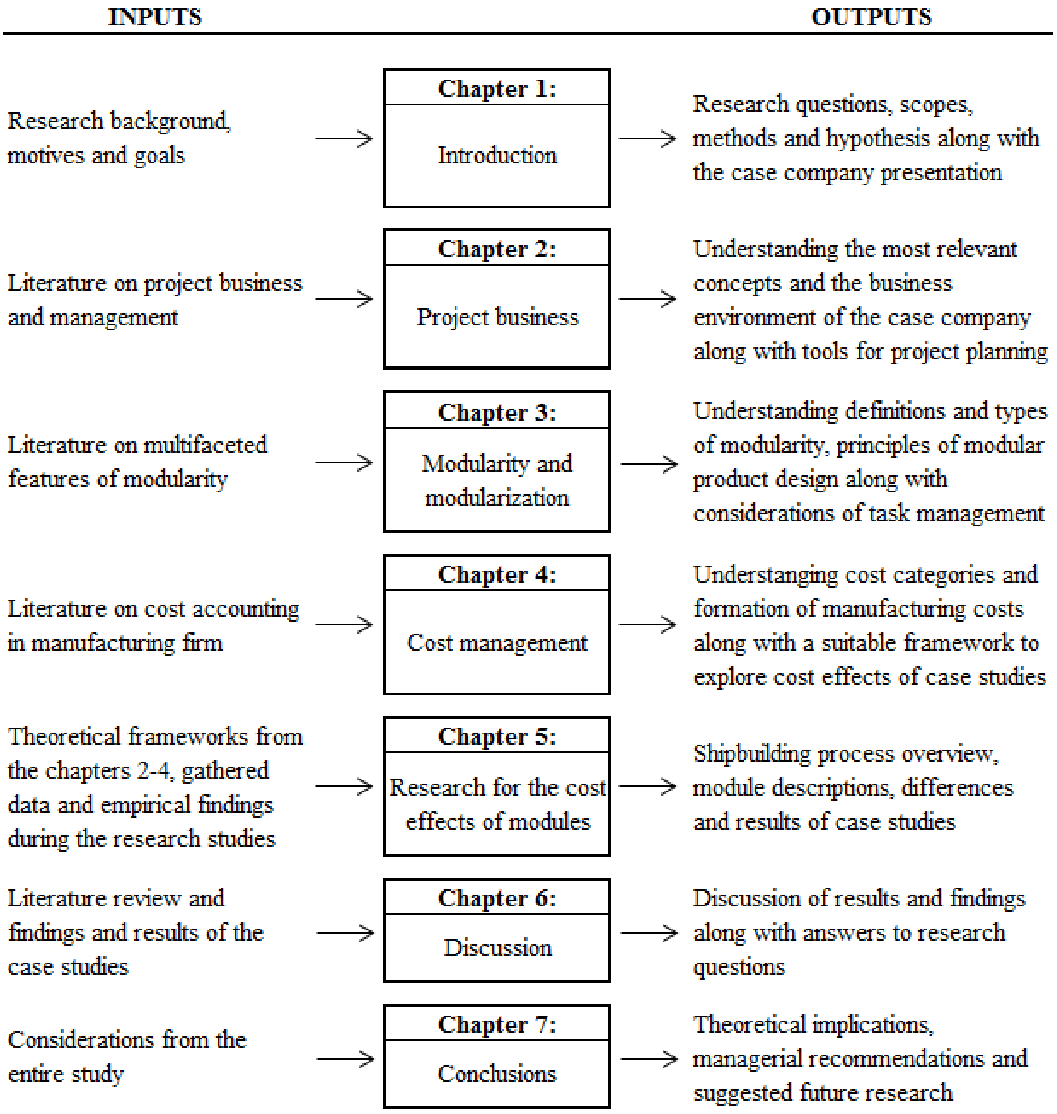


Figure 1. The structure of the thesis

1.5 Case company context

The case company for the research was Meyer Turku Oy which is a well-known shipyard located in Turku, in Southern Finland. Meyer Turku is one of the leading cruise ship builders in the world together with its two German sister shipyards

Meyer Werft in Papenburg and Neptun Werft in Rostock. Meyer Turku is specialized in building highly complex, innovative and environmentally friendly cruise ships, car-passenger ferries and special vessels. Turku has very long and successful traditions in the shipbuilding. There has been built ships in the Turku area since 1737. Meyer Turku is currently employing roughly 1,700 persons.

The company has had multiple owners in its history and the current owner of the shipyard is Meyer’s family from Germany. The latest changes in the ownership of the shipyard in Turku happened in September 2014 when Meyer Werft and the Finnish State together bought the shipyard from its previous owner called STX Europe (Turun Sanomat 2014). Soon after this, in May 2015, Meyer Werft bought its 30 % minority ownership of the shipyard from the Finnish State and has now the totally ownership of the shipyard (Turun Sanomat 2015).

At the moment the outlook for shipbuilding industry is on a really good level after couple of more quiet years. Meyer Turku has now a historic long order book of vessels which extends until the year 2024 including totally eight cruise vessels. The first two of them have been ordered by TUI Cruises, the next four vessels by Carnival and the latest two which will be one of the world’s biggest vessels have been ordered by Royal Caribbean. Meanwhile, Meyer Turku is investing heavily to the yard to be able stay at the top leader in the shipbuilding industry in the future. Number of employees in Meyer Turku will increase and the totally employment of the yard including its network will reach up to twenty thousands of employees in the next few years. (Turun Sanomat 2017)

2 PROJECT BUSINESS

Project business is often compared to a business that is based on repeating actions, known also as an industry of mass production. Artto et al. (2006, p. 28) discuss the main differences between project business and mass production. According their perceptions, project businesses are characterized by several common features such as flexibility, customer-tailored unique solutions, constant renewal and changes in the operating environment of companies. Furthermore, they add common features such as specified timetable and deadlines of actions, specified resources and budget based on project requirements as well as the uncertainty and risk related to the predictability of the results of the projects.

All those features are truly obvious in the case company context of shipbuilding industry as well. The business of creation of ships is a time-consuming activity with thousands of employees taking a part of it at different stages of the process. The shipbuilding project itself is a complex totality that consists of numerous of suppliers and activities which are shared inside the company and outsourced to the network. Generally, the total lead time of a shipbuilding process has been roughly one to three years (Taiminen 2000, p. 30-1).

2.1 Definition of the concept

According to Artto et al. (2006, p. 24-25) the concept of project has several and even partly contradictory definitions in the literature. Each definition depends on a perspective the project is reviewed through as well as a certain context and a target the project is established for. However, Artto et al. (2006, p. 25) discuss that one common characteristic emerges among several different definitions. They highlight the feature that every project has a specified starting and ending points, which make projects to be unique. In the context of this thesis project is defined in a similar way as Artto et al. (2006, p. 26) define it in their book of Projektiliiketoiminta (in English: Project Business): *“The project is a unique* *totality aiming towards a pre-determined objective with complex and interlinked tasks which are limited considering the time, costs and the scope of the project.”*

According to Artto et al. (2006, p. 31) the pre-determined objective of a project has three purposes. First, it is a reason the project is established for. Second, it defines a change as a result of the project realization. The change is considered as a product which is created during the project. Third, it is a basis to determine concrete objectives of the project: time, scope and cost (see figure 2).

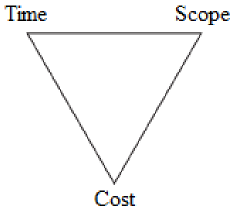


Figure 2. Objectives of a project (adapted from Artto et al. 2006, p. 32)

The previous figure illustrates the three obvious and distinctive objectives that every project has: time, scope and cost. The shape of a triangle signifies interdependencies between objectives and means that a change in a one objective will have an effect to other objectives. Time considers a timetable of the project by defining certain starting and ending points: When are we going to do? Scope considers an extent of the project: What are we going to do? Cost considers required budget and resources of the project: Who is going to do? Each objective has significant effects to the final result of the project. (Artto et al. 2006, p. 31-32)

2.2 Typical characteristics and trends

Projects tend to be very different in a many point of views. However, there occur basic similarities and principles that repeat from project to project regardless of the industry. Especially in the shipbuilding industry differences between projects might be really remarkable. Basic process flows of the project stay mainly the same between projects but produced products differ widely. In recent years Meyer

Turku has been able to build quite similar cruise vessels to the same ship owner which has created exceptional much repetition between the projects. This current series of sister vessels has been a historic long for a long time.

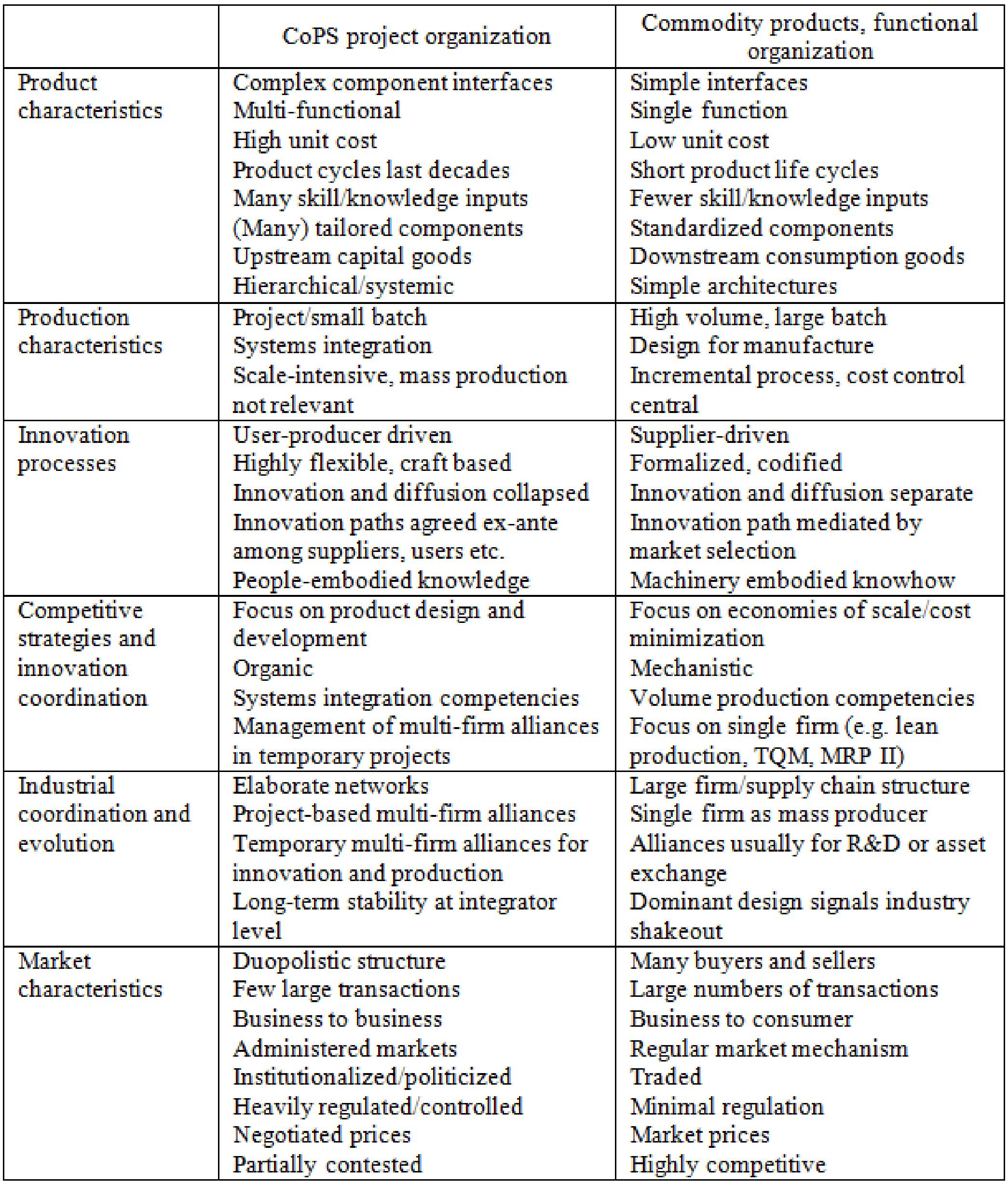
Hellström (2014) brings up the two most common characteristics of project business: its unique nature and complexity. He uses shipbuilding as an illustrative example of a complex capital good whose building process from raw materials to finalized end product consists of several sub-systems and supplier firms. Mandják & Veres (1998) have also similar thoughts. They use a DUC-model that summarizes the three common features of project business. The DUC concept has been abbreviated from the same concepts uniqueness and complexity as Hellström (2014) stated added by the concept of discontinuity.

2.2.1 Complex products and systems

Creation of complex products and systems (CoPS) is a concept that is often used in referring to the project business. It describes pretty well also the shipbuilding environment having several equal features in product, production and market characteristics as well as other characteristics and processes related to the business (see table 1). Complex products and systems such as ships differ from mass produced commodity goods in several ways, having mainly just opposite features. According to Hobday (1998) organizational structure of CoPS industry is characterized by project organization whereas commodity products have functional organization structure.

CoPS products, as Hobday (1998) discusses are typically produced in small batch sizes or one-off projects characterized by high value and technology, high customer-oriented engineering-intensity and customization purchased by a single user in business-to-business market, whereas commodity goods are produced in large batch sizes with advantages of scale economies. CoPS products emphasize the importance of skilled work done especially in activities of design, project management, systems engineering and integration. They are based mainly on many tailored, high unit cost components with complex interfaces needed by talented persons to handle and manage them. The whole creation process of complex products and systems is a long-lasting process from the idea to its completion based widely on a support from the network of many subcontractors working together simultaneously. (Hobday 1998)

Table 1. CoPS versus mass production (adapted from Hobday 1998)



	CoPS project organization	Commodity products, functional organization
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 Standardized components Downstream consumption goods Simple architectures
Production characteristics	Project/small batch Systems integration Scale-intensive, mass production not relevant	High volume, large batch Design for manufacture Incremental process, 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 Formalized, codified Innovation and diffusion separate Innovation path mediated by market selection Machinery embodied knowhow
Competitive strategies and innovation coordination	Focus on product design and development Organic Systems integration competencies Management of multi-firm alliances in temporary projects	Focus on economies of scale/cost minimization Mechanistic Volume production competencies Focus on single firm (e.g. lean production, TQM, MRP II)
Industrial coordination and evolution	Elaborate networks Project-based multi-firm alliances Temporary multi-firm alliances for innovation and production Long-term stability at integrator level	Large firm/supply chain structure Single firm as mass producer Alliances usually for R&D or asset exchange Dominant design signals industry shakeout
Market characteristics	Duopolistic structure Few large transactions Business to business Administered markets Institutionalized/politicized Heavily regulated/controlled Negotiated prices Partially contested	Many buyers and sellers Large numbers of transactions Business to consumer Regular market mechanism Traded Minimal regulation Market prices Highly competitive

2.2.2 Systems integration

Customer orientation has gained a big share of attention nowadays which seems in focusing on more and more on services among companies' product offerings. The growing emphasis on service offerings is commonly described as a shift from products to services (Hellström 2014). Some authors have described the shift as a change from product-centric to customer-centric companies (Galbraith 2002) or from product bundles to relational processes (Tuli et al. 2007). According to Hellström & Wikström (2005) effects of customer orientation to the management paradigms are recognizable. They argue that earlier the main emphasis and a way of thinking were just on creating the product with tight schedule, budget and quality while nowadays more emphasis is put on creating value for the customers.

According to Hellström & Wikström (2005) increasingly growing service aspect has created the concept of **systems selling** that considers the general movement towards service management and service-led projects. Davies et al. (2007) define the concept as *"the provision of products and services integrated systems that provide solutions to customer's operational needs"*. Consequently, offerings of delivery projects consist to an increasing extent of a combination of goods and services and especially the share of services has increased remarkable. The aim of the phenomenon towards **integrated solutions** is to offer whole solutions instead of selling only physical goods (Hellström 2014, Davies 2004).

Davies et al. (2007) discuss two types of organizations: **the vertically-integrated systems seller** and **the systems integrator** (see figure 3). They describe the former as an organization that produces all or most of the system's product and service components by themselves. The latter one acquires components from external suppliers and coordinates only their integration by themselves. In a case of the systems integration Davies et al. (2007) highlight the advantages that arise from interface standardization, modularity in component supply and ability to co-operate with several vendors. Hellström & Wikström (2005) emphasize an ability to practice systems integration as one of the key success factors of project business in the future.

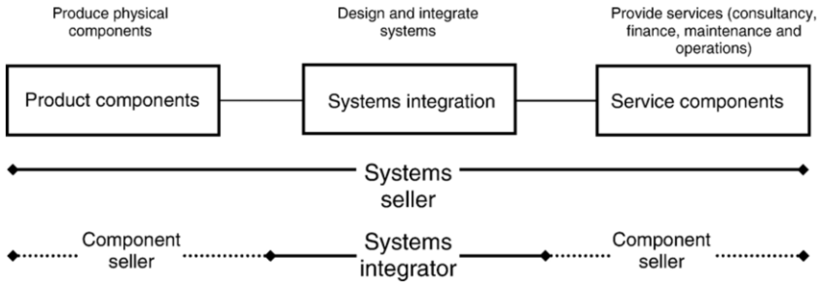


Figure 3. Systems seller versus systems integrator (Davies et al. 2007)

2.2.3 Production paradigm

Project businesses such as shipbuilding are strongly characterized by the feature of engineering-intensiveness driven by specific customer requirements and deep customer orientation (Hobday 1998). Hence, an engineering to order (ETO) production paradigm is a correct approach to deal with in this context. Haug et al. (2009) highlight ETO companies to offer products which are engineered to fulfill specific customer requirements. In shipbuilding, the customer's voice is so strong that the design work of a ship obeys accurately customer's urge. Generally, design of a certain vessel differs much from the previous ones which makes it challenging to reuse design work and excludes also possibility to do it beforehand.

In this context the concept of customer order de-coupling point (CODP) is also necessary to outline to understand the basic nature of design and manufacturing processes in ETO deliveries. CODP is sometimes called also as an order penetration point (OPP) or a late-point differentiation (LPD) having the equal features (see e.g. Olhager 2003, Sanchez 1999). Customer order de-coupling point is a point in manufacturing process where the certain customer order is considered for the first time. Before the CODP (upstream of the CODP), manufacturing process is based only on forecasts and is not dependent on any customer requirements. A certain customer order is linked to the manufacturing process at that point and differentiated thereafter (downstream of the CODP) complying with customer voice. (Wikner & Rudberd 2005, Haug et al. 2009)

The figure 4 below illustrates the positions of CODPs (triangles in the figure) in a case of ETO and other general production paradigms: make to order (MTO), assemble to order (ATO) and make to stock (MTS). As can be seen, in ETO deliveries CODP is located very early in the manufacturing process compared to other production paradigms. For example, MTS products are mainly those mass-produced commodity goods with high sales volumes such as mobile phones. They are designed completely beforehand and delivered to a certain customer straight from the warehouse. In these cases, the total lead time from the customer point of view is really short compared to ETO deliveries. Olhager (2003) discusses ATO delivery to be a typically related to production of modular products with a short delivery lead time and efficient manufacturing operations.

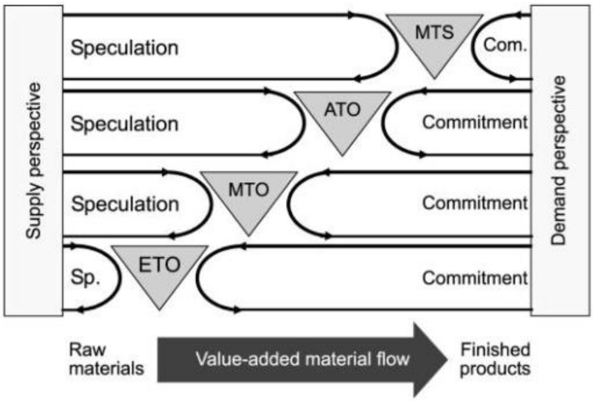


Figure 4. Production paradigms and CODPs (Wikner & Rudberg 2005)

The previous figure is missing configure to order (CTO) production paradigm that has favorable features the shipbuilding industry should try to achieve. It is located in between of ETO and MTO production paradigms. In CTO deliveries, earlier done design work can be partly utilized or it can be easily configured to the following project. Thus, the total lead time of CTO deliveries would be remarkably shortened compared to pure ETO deliveries. One can find similarities in principles of CTO and thoughts of Hellström & Wickström (2005) when they discuss the changing nature of project management towards increased standardization of product and process architectures while enabling more flexibility. Furthermore, CTO benefits from the modularity utilization that is a consequence of standardization and will be discussed later more.

Positioning of customer order de-coupling point in a delivery chain depends on several factors. Olhager (2003) has identified three main categories which affect to the positioning of CODP: market, product and production characteristics (see figure 5). The figure illustrates how they are related to each other and what are their effects to delivery and production lead times. On the left side of the figure can be seen features influencing for each category.

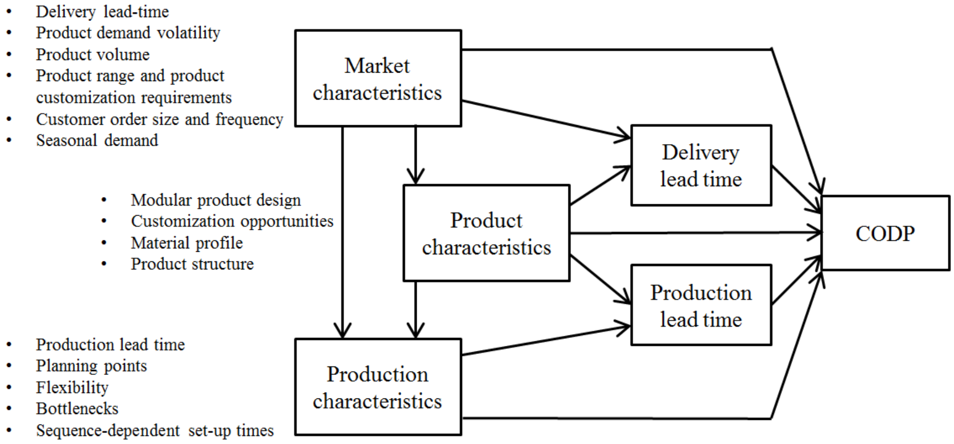


Figure 5. Positioning of CODP (adapted from Olhager 2003)

2.3 Project planning tools

Project management includes operations of planning and coordinating of project tasks and resources during the project planning and execution (Ulrich & Eppinger 2012, p. 380). Successful project management needs tools and techniques for supporting and managing of such operations. In this chapter the most relevant project planning tools will be introduced in relation to their suitability for the scope of the thesis and modularity purposes. Deep understanding of the project tasks and timetables as well as the project's overall execution order is really essential areas in early planning stages related to the module usage.

2.3.1 Work breakdown structure

Work breakdown structure (WBS) is a traditional project planning tool. According to Artto et al. (2006, p. 112) the aim of WBS is to subdivide a project into smaller and better manageable units in order to improve the management of project scope, tasks and resources of the project. As a result of WBS, it creates a hierarchical description of all the tasks required by the project (see figure 6). Artto et al. (2006, p. 112) discuss that the idea of WBS has evolved from the product breakdown structure (PBS) where a product has divided hierarchically into parts and further to components in order to improve the product structure management.

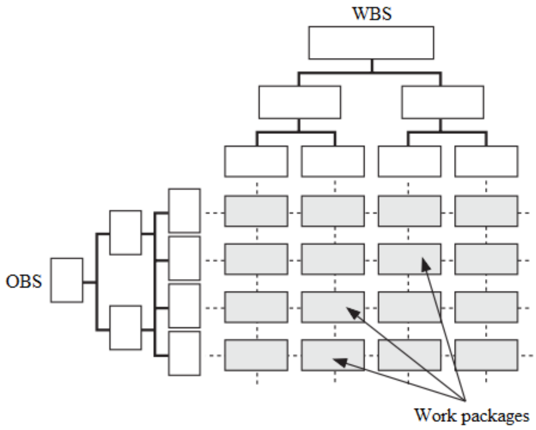


Figure 6. Work breakdown structure (adapted from Artto et al. 2006, p. 143)

Hellström (2005) highlights the importance to understand work and product breakdown structures in the context of product architecture and modularity utilization purposes. Artto et al. (2006, p. 112) describe project tasks as product components that will be produced during the project execution. They highlight that the hierarchical description of product structure does not define the workload that each part or component requires to be completed. Thus, they use a concept of work package in order to relate just to the amount of work that each project task requires to be completed. In this context, Artto et al. (2006, p. 112) highlight also the importance of organization breakdown structure (OBS) that divides the whole organization into smaller parts in relation to the work packages of a project.

2.3.2 Critical path

Critical path method (CPM) is considered also as an essential project management tool. According to Ulrich & Eppinger (2012, p. 384) CPM considers precisely dependencies among project tasks during the project execution. They discuss different types of tasks: some of them which should be arranged sequentially, those which can be arranged in parallel and a combination of them i.e. iteratively coupled. The critical path (see figure 7) includes the longest chain of tasks which are dependent of each other, so it determines the execution order of tasks. On the critical path the following task cannot be executed before the previous one has been completed. If there are delays within one or more tasks in the critical path, the whole process will be delayed due to those single delays. (Artto et al. 2006, p. 132; Ulrich & Eppinger 2012, p. 384-385)

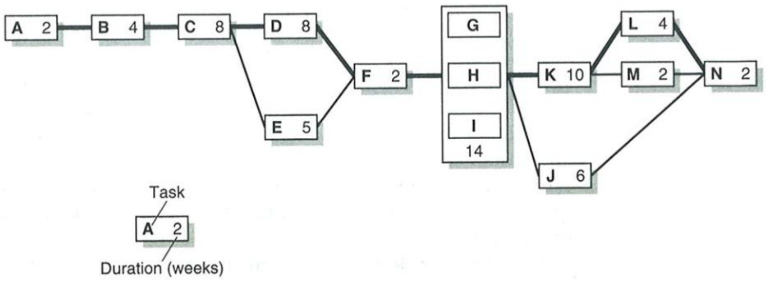


Figure 7. Critical path (Ulrich & Eppinger 2012, p. 384)

Each task requires a certain period of time to be completed. By summing all these single durations together, one will get the minimum time needed to complete all the tasks included to the critical path (Ulrich & Eppinger 2012, p. 385). In the previous figure, the critical path is illustrated with the thicker line and the squares illustrate tasks with information of required time to get each task completed.

2.3.3 Gantt chart

Ulrich & Eppinger (2012, p. 384) describe the Gantt chart as a traditional tool to represent visually timing of project tasks. It consists of a timeline at the bottom of the chart and project tasks placed under each other at the left bar of the chart (see figure 8). The vertical black line in the middle of the chart displays current date. The black dyed fraction illustrates the completed share of the certain task at the moment. As can be noted, tasks A-C are completed while tasks F-N are still waiting to be started. Task D is delayed from the planned schedule whereas task E is ahead of the schedule and already completed.

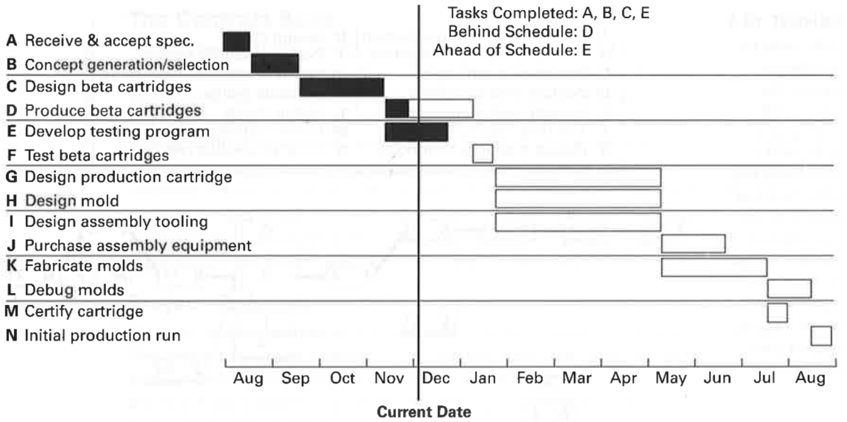


Figure 8. Gantt chart (Ulrich & Eppinger 2012, p. 383)

Critical path illustrates exact dependencies between different project tasks and tells which of them can or should be done either in sequential, parallel or coupled, while the Gantt chart does not do it so explicitly. One cannot get to know further information of execution order of overlapped tasks from the information provided by the Gantt chart. (Ulrich & Eppinger 2012, p. 383)

3 MODULARITY AND MODULARIZATION

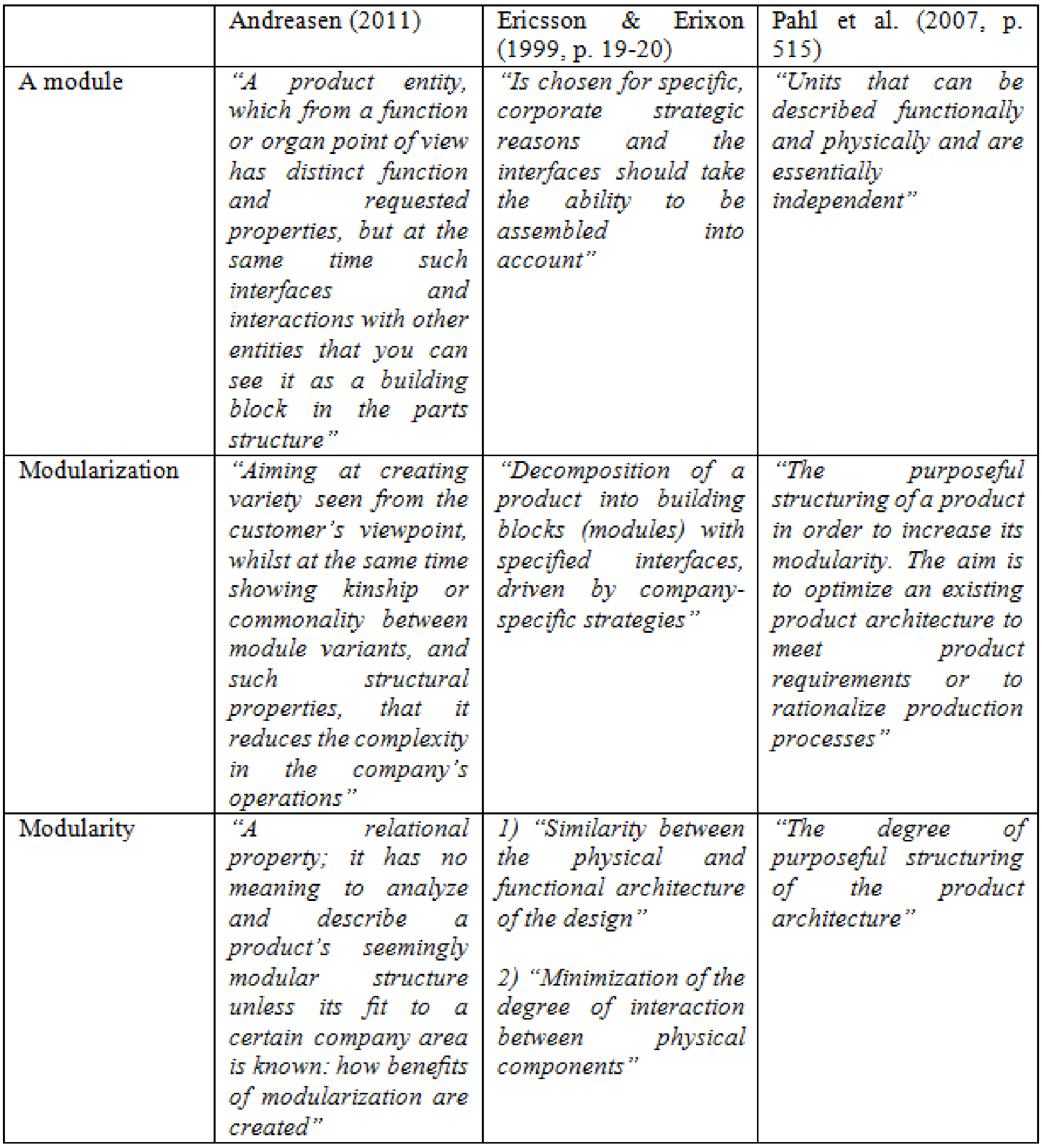
This chapter introduces a multidisciplinary context of modularity. It can certainly be noted that modularity is a concept that can be found in wide variety of different contexts nowadays, including both technical aspects and business aspects (Stjepandić et al. 2015, p. 389). According to Stjepandić et al. (2015, p. 390) technique is probably the first and the most general context in one's mind when considering modularity. They explain modularity to appear also in several other areas such as in education, science, management, organization, financial services and the public administration. The idea of modularity as an engineering and management domain has been emerged since the 1960s when the trendsetter in modularity was a computer industry through the first modular designed computers (Stjepandić et al. 2015, p. 390).

3.1 Definitions of the concepts

Module, modularity, modularization, modular design, modular product platform and sub-assembly are examples of very general concepts in an industrial environment nowadays. In the current literature can be found a great amount of different definitions for the concepts related to the modularity (see e.g Andreasen 2011; Ericsson & Erixon 1999, p. 19-20; Lehtonen 2007; Pakkanen 2015; Pahl et al. 2007, p. 515) but there is still a lack of one common and generally accepted discrete definition for each concept that is able to replace all those various available definitions.

Usually definitions for the concepts depend on a certain company context or a person and his or her position who is asked from. See table 2 to view different definitions for the concepts of a module, modularization and modularity which have been gathered from three different publications. As can be seen, each definition is individual although there are also similarities in definitions.

Table 2. Definitions for a module, modularization and modularity



	Andreasen (2011)	Ericsson & Erixon (1999, p. 19-20)	Pahl et al. (2007, p. 515)
A module	*"A product entity, which from a function or organ point of view has distinct function and requested properties, but at the same time such interfaces and interactions with other entities that you can see it as a building block in the parts structure"*	*"Is chosen for specific, corporate strategic reasons and the interfaces should take the ability to be assembled into account"*	*"Units that can be described functionally and physically and are essentially independent"*
Modularization	*"Aiming at creating variety seen from the customer's viewpoint, whilst at the same time showing kinship or commonality between module variants, and such structural properties, that it reduces the complexity in the company's operations"*	*"Decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific strategies"*	*"The purposeful structuring of a product in order to increase its modularity. The aim is to optimize an existing product architecture to meet product requirements or to rationalize production processes"*
Modularity	*"A relational property; it has no meaning to analyze and describe a product's seemingly modular structure unless its fit to a certain company area is known: how benefits of modularization are created"*	*1) "Similarity between the physical and functional architecture of the design"* *2) "Minimization of the degree of interaction between physical components"*	*"The degree of purposeful structuring of the product architecture"*

3.2 Types of modularity

As the previous chapter introduced, there are several different definitions for the main concepts related to the modularity. Thus, it is also natural consequence that different categorizations of modularity occur as well. Lehtonen (2007) has explored widely current literature on modularity and discusses in his dissertation that there are mainly two types of modularity: M-modularity and life cycle modularity which will be presented in the following chapters.

3.2.1 M-modularity

Lehtonen (2007) discusses the idea of M-modularity to be influenced by Borowski in 1961 in his book of Das Baukastensystem in der Technik and explains that the initial letter ‘M’ in the concept of M-modularity refers to the Finnish word configuration, *muuntelu*. Consequently, he states that M-modularity emphasizes configurability and enables to create product variations. Lehtonen’s (2007) definition for the M-modularity is based on four axioms:

1. A module has a predefined interface
2. A module is a part of a modular system
3. A modular system has modules only in one level
4. Modules are connected to a modular system in six different ways

According to Lehtonen (2007) in M-modularity **a module** is defined as *“a block (any assembly of the product or part of the system) is a module if it has an assigned interface and it is a part of a modular system”*. He continues defining **a modular system** as *“a system consisting of blocks which involves the interchangeability of the blocks”*.

As it is stated in the four axioms below and in definitions of M-modularity, a module belongs to a modular system and it can be interchanged. Lehtonen (2007) explains that modules’ interchangeability is based on the research done by Pine (1993, p. 201) where he explained that there exist six different ways to change modules in a modular system (see figure 9).

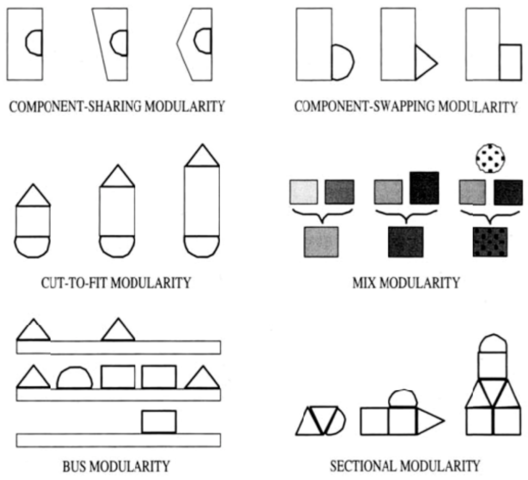


Figure 9. Types of modules interchangeability (Pine 1993, p. 201)

Pakkanen (2015) discusses briefly in his dissertation each type of interchangeable modules that were initially determined more accurately by Pine (1993, p. 200-210). Pakkanen's descriptions for each type are presented in the following table 3.

Table 3. Description of interchangeable module types

Type	Description
Component-sharing modularity	Use of the same component across multiple products.
Component-swapping modularity	Complement of the component-sharing modularity. Components are paired with the same basic product and as many products as there are components to be swapped can be created.
Cut-to-fit modularity	One or more of the components are continually variable within preset or practical limits.
Mix modularity	Use of any of the types above. Mixing components together in a way something different is created.
Bus modularity	Use of the standard structure in which a number of different components can be attached.
Sectional modularity	Allows the configuration of any number of different types of components which have standard interfaces in arbitrary ways. Enables the greatest degree of variety and customization.

3.2.2 Life cycle modularity

Another type of modularity, according to Lehtonen (2007) is the life cycle modularity. He discusses the life cycle modularity neither to enable configuration nor product variety as they are in the core of M-modularity. In the life cycle modularity, modularity is related to the life cycle of the product and it is based on different reasons. According to Lehtonen (2007) three types of life cycle modularity exists (see figure 10):

1. Modularity based on reasons of manufacturing
2. Modularity based on reasons of maintenance
3. Modularity based on logistical reasons

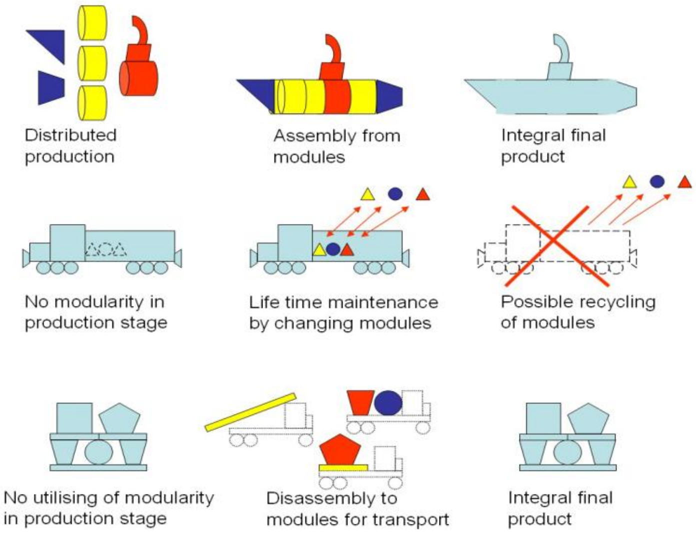


Figure 10. Types of life cycle modularity (Lehtonen 2007)

The first row of the previous figure describes modularity that is based on the reasons of manufacturing and illustrates it by using a submarine as an example. In such an example modularity appears only at the manufacturing stage in a way the manufacturing of submarine is decentralized into different locations. The integral final product is assembled from these modules after they are manufactured and brought together. (Lehtonen 2007)

The second row of the figure presents the maintenance based reasons of life cycle modularity. In such a locomotive example, modularity is considered by creating replaceable rack-type modules that consists of critical and easily breakable parts. In doing so, the maintenance operations are easy and simple to do by changing only the broken module into a new one. (Lehtonen 2007)

Life cycle modularity based on the logistical reasons is illustrated in the last row of the figure. Lehtonen (2007) uses an example from the shipbuilding environment. He explains an interior design of a restaurant of passenger ship to be constructed and assembled on the site of production facilities. After assembling the entity at the factory, it is disassembled to modules due to the transport purposes to the yard and assembled again in the desired location inside the vessel.

Lehtonen (2007) highlights that in the life cycle modularity the product structure is completely static excluding the possibility of variation in the product structure. He explains these products not to even have a modular system due to the characteristics of life cycle modularity. Life cycle modularity can be summarized into the above presented three types of modularity and a need for being able to manage interfaces between modules (Lehtonen 2007).

Graf (2016) gives criticisms for the presented ways to categorize modularity and argues that the M-modularity should not be seen as a modularity type. He suggests that there should exist only life cycle modularity or systematical modularity. Graf (2016) explains that different ways to combine modules together is not a modularity type and thus he rather calls it as only a type to join modules together.

3.3 Product design modularity

The biggest share of literature on modularity is focused on product design modularity because of its technical aspect (Campagnolo & Camuffo 2010). According to Hellström & Wikström (2005) modularity is a well-known and highly advanced practice among high-volume industries due to the possibility to achieve economies of scale. Stjepandić et al. (2015, p. 389) state that modularity is an effective way to offer several product variations and customized products from standards to unique ones that meet the specified customer needs. However, in a project business there exist challenges in utilizing of modularity due to the previously presented characteristics such as complex products structures and continuously changing complex business environment. This chapter provides an overview to the topic of product design modularity by discussing its backgrounds, different perspectives and generally known effects.

3.3.1 Evolution

Companies’ operating environment is continuously changing, and companies have to change within the market change in order to stay competitive and be capable to answer for the customers’ needs. This market-oriented pressure towards companies during the past decades has been one remarkable reason in the evolution of product design modularity. For manufacturing companies market forces have affected by increasing complexity and amount of different product variants. At the same time companies’ efficiency has decreased because they have been forced to spend more time on non-value-adding activities and create so-called ad-hoc solutions and specially built products in order to be able to meet rapidly changing specific customer needs. (Ericsson & Erixon 1999, p. 1-3)

Stjepandić et al. (2015, p. 392) state that principles of modular product design arise from the advantages of customization and standardization. Lampel & Mintzberg (1996) see customization and standardization as opposite forces and modularity as a way to balance against them. However, roots of mass customization lie on its first definition done by Davis (1987) when he used the concept in a position where “*the same large number of customers can be reached as in mass markets of the industrial economy, and simultaneously they can be treated individually as in the customized markets of preindustrial economies*”. Later Victor & Boynton (1998) have explained that mass customization means company’s ability to systematically adapt their processes in a way they produce products that customers are willing to buy in unstable and rapidly changing market environment. Tseng & Jiao (2001) and Haug et al. (2009) have highlighted the general principle of mass customization to be the ability to offer customized products and services at a price and efficiency near of mass produced ones.

According to Pakkanen (2015) standardization enables modularization. In a context of product modularity, standardization is reasonable to define through a component standardization point of view, similarly to Ulrich & Eppinger (2012, p. 189) when they defined it as *"the use of the same component or chunk in multiple products. If a chunk implements only one or a few widely useful function elements, then the chunk can be standardized and used in several different products."* Thirteen years earlier Perera et al. (1999) have offered another definition arguing that *"the term component standardization refers to the situation in which several components are replaced by a single component that can perform the functions of all of them."* They (Perera et al. 1999) identified three possible use cases of component standardization: component standardization within a product, component standardization among products and component standardization among product generations.

Pakkanen (2015) presents several advantages and some disadvantages of standardization (see figure 11), which he has collected from the articles written by Perera et al. (1999) and Wacker & Treleven (1986). Effects have been categorized into the figure according to different phases of a product life cycle. From the figure can be seen several relations to costs: both advantages and disadvantages. Standardization of components has mainly positive effects in terms of costs by decreasing committed costs at different stages of the product life cycle. Majority of positive effects have been identified at the manufacturing stage of product life cycle. Some of those negative cost effects at a certain stage may decrease costs at another later stage remarkably. For example, increased effort for design work of a component at the early stage of product life cycle may simplify its manufacture or assembly work significantly at further stages which creates remarkable cost savings. It should also be noted that listed effects in the figure cannot directly be applied to every single case and product.

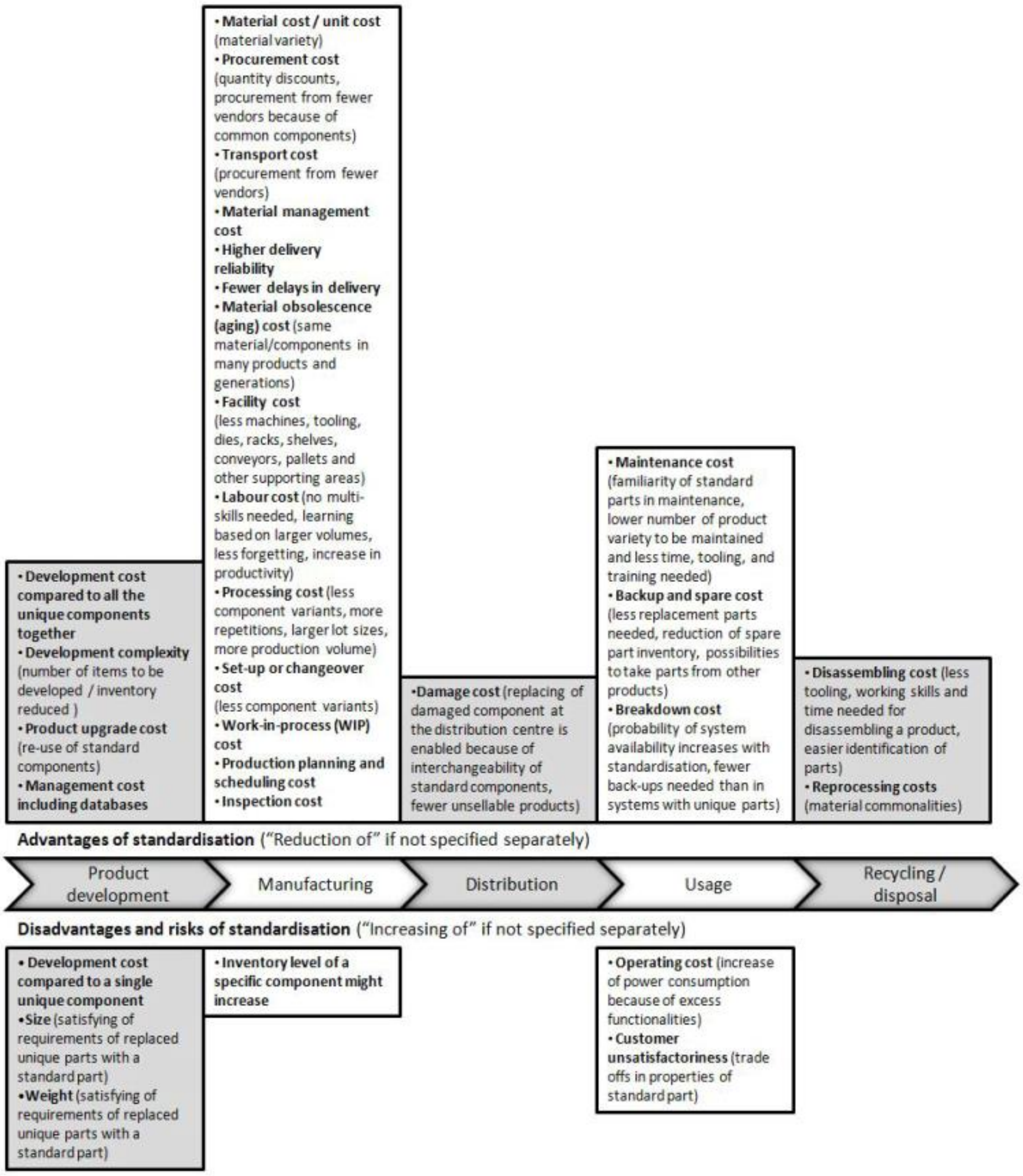


Figure 11. Effects of component standardization (Pakkanen 2015)

3.3.2 Perspectives of modular product design

Campagnolo & Camuffo (2010) explored comprehensively 125 different management studies based on modularity between the years 1986 and 2007. They ended up in a conclusion that there exist three different points of view from which the current literature considers product design modularity: functional perspective, life cycle perspective and mixed perspective. Furthermore, they recognized that the categorization into these groups follows the corresponding chronological evolution of literature on product design modularity. Following chapters will discuss each perspective in more details.

Functional perspective

According to Campagnolo & Camuffo (2010) the functional perspective observes the modular product design from a technical architecture point of view looking at components, functions and interactions. They emphasize to concentrate on the relationship between modules and functions and the links between module interfaces. Initially the functional perspective dates to Ulrich's (1995) survey about the product architecture where he discusses the relationship between a function and a physical component of the product. He explains that product architecture is *"the scheme by which the function of a product is allocated to physical components"*. Parallel definition has also done by Fujimoto (2007) stating that *"product architecture is an aspect of design concept comprising of components. Product architecture is a description of how to put parts together."* See figure 12 to view an illustration of the product architecture.

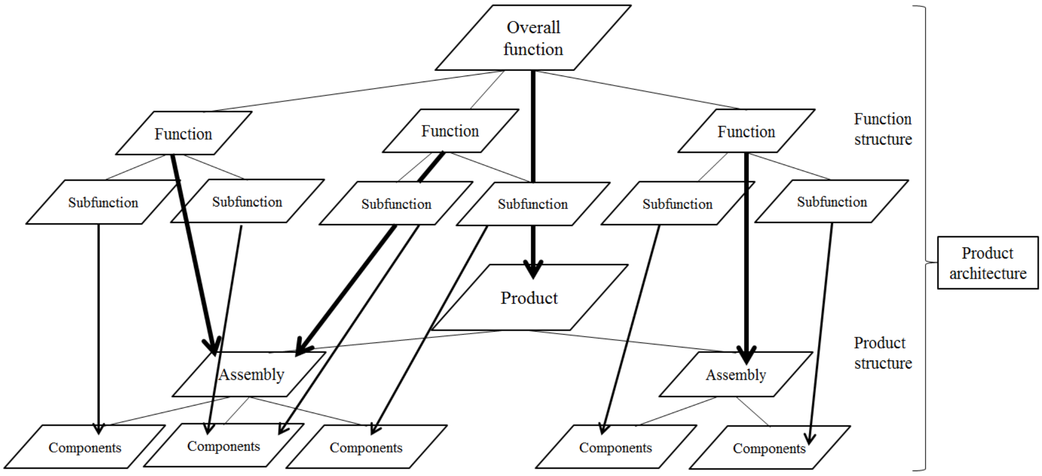


Figure 12. Product architecture (adapted from Pahl et al. 2007, p. 514)

Ulrich (1995) explains that the product architecture has following three main characteristics: the arrangement of functional elements, the mapping from functional elements to physical components and the specification of the interfaces among interacting physical components. He states that the function of a product can be explained from its operations by concentrating on what does the product do in comparison to its physical characteristics and talks about a function structure which he means the arrangement of functional elements and their interconnections. Figure 13 illustrates function structure of a trailer as an example.

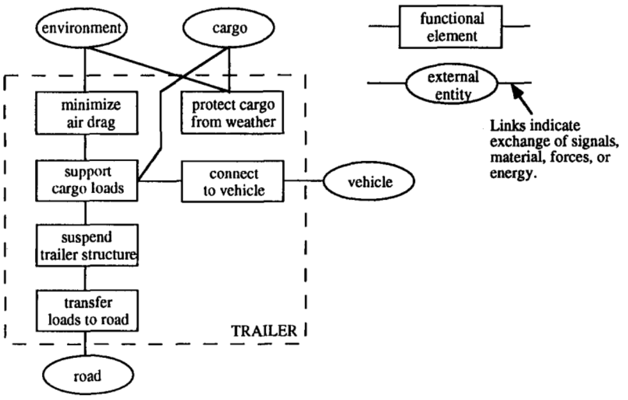


Figure 13. Function structure (Ulrich 1995)

According to Ulrich (1995) the mapping from each functional element to the physical component is either one-to-one, many-to-one or one-to-many. Based on the functional perspective and the simplicity or complexity in mapping, there exist two different product architectures: **a modular architecture** and **an integral architecture**. Figure 14 illustrates both architectures using trailer as an example.

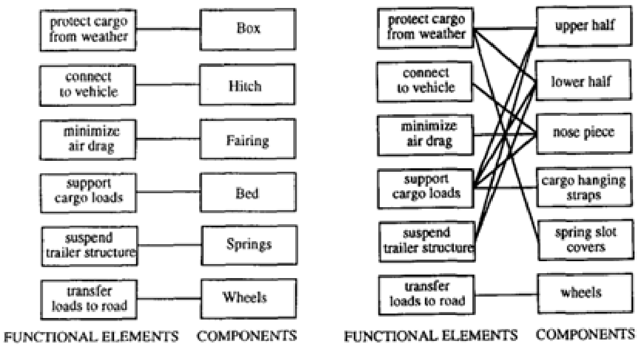


Figure 14. Modular and integral architectures (adapted from Ulrich 1995)

Modular architecture includes a simple one-to-one mapping from the functional elements to the physical components while an integral architecture includes a complex mapping between them (Ulrich 1995). Sako (2003) describes the division of product architectures into modular or integral architecture to be conceptually powerful and argues it to be difficult to do in practice. Furthermore, Ulrich (1995) continues explaining that modular architecture has de-coupled interfaces between each component while integral architecture has coupled interfaces (see figure 15). Differences in interfaces Ulrich (1995) illustrates arguing that there is a coupled interface between two components if changes in one component make the overall product unable to work correctly or totally unworkable until the other component is changed as well.

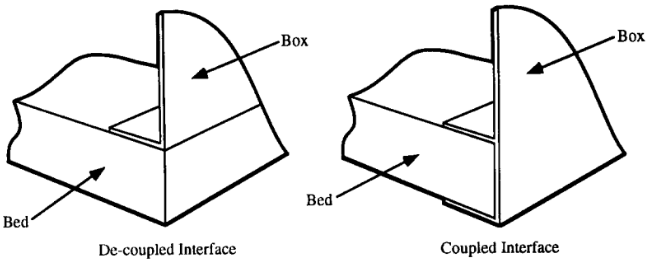


Figure 15. Categorization of interfaces (Ulrich 1995)

The last characteristic i.e. the specification of the interfaces among interacting physical components specifies the primary interactions across the component interfaces, according to Ulrich (1995). He explains that they may be either a geometric or a non-contact such as geometric or infrared based communication.

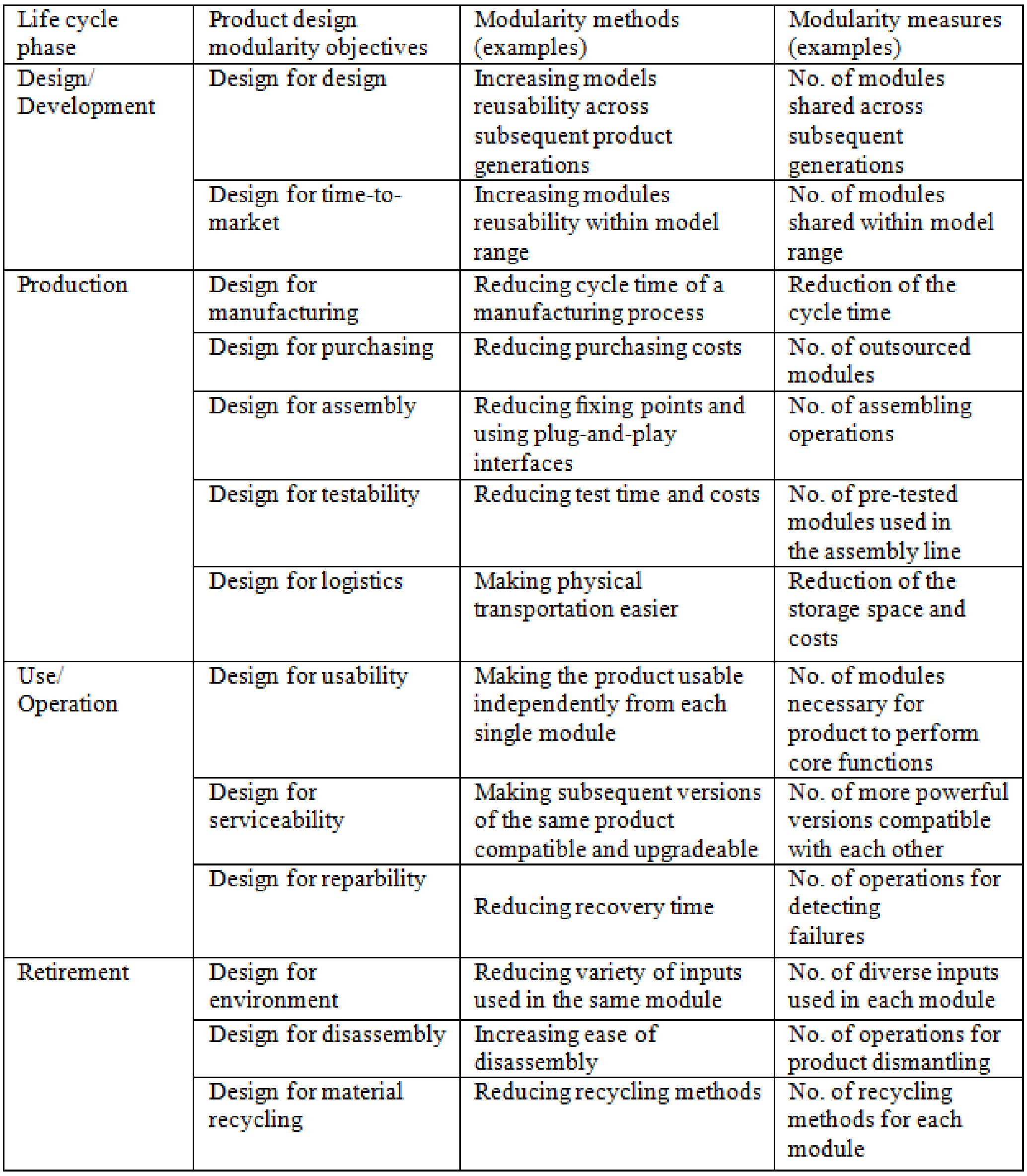
Life cycle perspective

Product life cycle is a time period which covers all the phases that product will pass during its lifespan. Pahl et al. (2007, p. 2-3) discuss that every single product life cycle starts either from a market need or a problem or a new idea from a company and goes through many steps and ends after energy recovering or recycling of the product. During the phases of product life cycle, raw materials are converted into economic products, delivered to customers with added value and consumed by them. Generally, the product life cycle includes design and development, production, use and retirement phases (Fixson 2003).

Life cycle perspective of the modular product design observes the topic from a process point of view. In the life cycle perspective, product modularity is stressed by modularity objectives during the life cycle phases and it answers for the question: “Modularity for what?” Life cycle perspective enables to end up in different design solutions even to the same product depending on the life cycle phase the product modularization is done. The final product design depends on the company’s specific objectives at the certain life cycle phase. Furthermore, company’s objectives for the product design modularity depend also on other product, market and industry characteristics. (Campagnolo & Camuffo 2010)

Campagnolo & Camuffo (2010) explain that in the life cycle perspective company’s objectives determine also their definition for the product modularity and define operations needed to achieve them. The following table 4 below consists of life cycle phases and descriptions of effects how the life cycle perspective affects to modular product design at each phase. There are also listed objectives and methods as well as examples how to measure product modularity in the figure. As an example, at a design and development phase the objective of product design modularity may be a design for design, which means that created design models will be more reused across subsequent product generations. In such a case, modularity can be measured in the numbers of modules shared across following product generations. At the production phase the objective of product design modularity may be a design for manufacturing with the aim of reducing cycle time of a manufacturing process. In this example, modularity can be measured by the reduction of cycle time.

Table 4. Life cycle based modularity examples (Campagnolo & Camuffo 2010)



Life cycle phase	Product design modularity objectives	Modularity methods (examples)	Modularity measures (examples)
Design/ Development	Design for design	Increasing models reusability across subsequent product generations	No. of modules shared across subsequent generations
	Design for time-to-market	Increasing modules reusability within model range	No. of modules shared within model range
Production	Design for manufacturing	Reducing cycle time of a manufacturing process	Reduction of the cycle time
	Design for purchasing	Reducing purchasing costs	No. of outsourced modules
	Design for assembly	Reducing fixing points and using plug-and-play interfaces	No. of assembling operations
	Design for testability	Reducing test time and costs	No. of pre-tested modules used in the assembly line
	Design for logistics	Making physical transportation easier	Reduction of the storage space and costs
Use/ Operation	Design for usability	Making the product usable independently from each single module	No. of modules necessary for product to perform core functions
	Design for serviceability	Making subsequent versions of the same product compatible and upgradeable	No. of more powerful versions compatible with each other
	Design for reparbility	Reducing recovery time	No. of operations for detecting failures
Retirement	Design for environment	Reducing variety of inputs used in the same module	No. of diverse inputs used in each module
	Design for disassembly	Increasing ease of disassembly	No. of operations for product dismantling
	Design for material recycling	Reducing recycling methods	No. of recycling methods for each module

Hsueh (2011) presents another way to categorize product life cycle. According to him product life cycle can also be divided into phases of introduction, growth, maturity and decline (see figure 16). Life cycle phases are placed on the horizontal axis while the vertical axis figures out the demand quantity of a product at different phases of the life cycle.

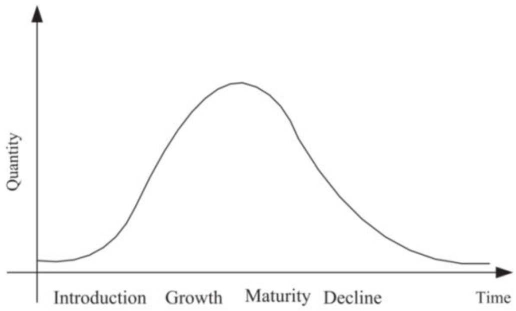


Figure 16. Product life cycle stages (adapted from Hsueh 2011)

Campagnolo & Camuffo (2010) discuss also a viewpoint of modularize a product during at some of these phases. They argue that at the later phases of product life cycle the product modularization is planned to do, the more limited is company's capabilities to affect to the product architecture and achieve benefits from product modularity compared to the modularization done at early phases.

Mixed perspective

Mixed perspective of the modular product design combines the two perspectives presented above and hence Campagnolo & Camuffo (2010) call it as a double perspective. According to them, mixed perspective includes considerations from both the product architecture and product modularization process point of views in order to get an answer for the question: "How can a product be modularized?"

Baldwin & Clark (1997) reached mixed perspective of product design modularity by discussing visible design rules and hidden design parameters. According to them visible design rules are decisions that include essential information and have a strong effect to module's product design, and hence further also to design decisions during the design process. Visible design rules should be done as early as possible in the design process and shared freely among all participants of the process. Hidden design parameters are almost the opposite for visible design rules including decisions that do not have effects to the design beyond the local module. Information included in hidden design parameters can thereby be defined and changed easily several times during the design process. Moreover, they do not need to be shared across all the members of a design team due to their insignificant nature. (Baldwin & Clark 1997; Campagnolo & Camuffo 2010)

Sako (2003, p. 231-232) discusses a criticism regarding on the functional and life cycle perspectives and highlight three unclear controversies. Firstly, she explains it difficult to measure the level of product modularity in cases where characteristics of product architecture are in contradictory. For example, if the product architecture has a combination of characteristics such as one-to-one mapping from function to component and coupled interfaces, there occurs disagreement on measuring the level of product modularity. Corresponding occasion occurs if the product architecture has many-to-one mapping from function to component and de-coupled interfaces. According to Sako (2003, p. 231-232) examples are in contradiction to previously presented division of product architectures and their features.

Secondly, Sako (2003, p. 232) highlights ambiguities considering which is the correct size of a module. She explains that complex products may consist of thousands of components and states that a module may be formed from a bundle of components. It is, however, not generally obvious which is an ideal size of a module and one can determine it mainly case by case. Thirdly, Sako (2003, p. 232-233) discusses difficulties to define a single optimal decomposition of products due to the effects of different life cycle objectives. As discussed already earlier and as Sako (2003, p. 232-233) argues modularity at design, production, use or even at retirement phase cause different objectives. Hence, different outcomes of product design appear which cause complications in coordinating between them.

As stated, mixed perspective considers modularization and design processes of modular products. In the current literature can be found several modularization approaches, processes and design supports in order to create totally new modular product architecture or rationalize current product variety (see e.g. Pakkanen

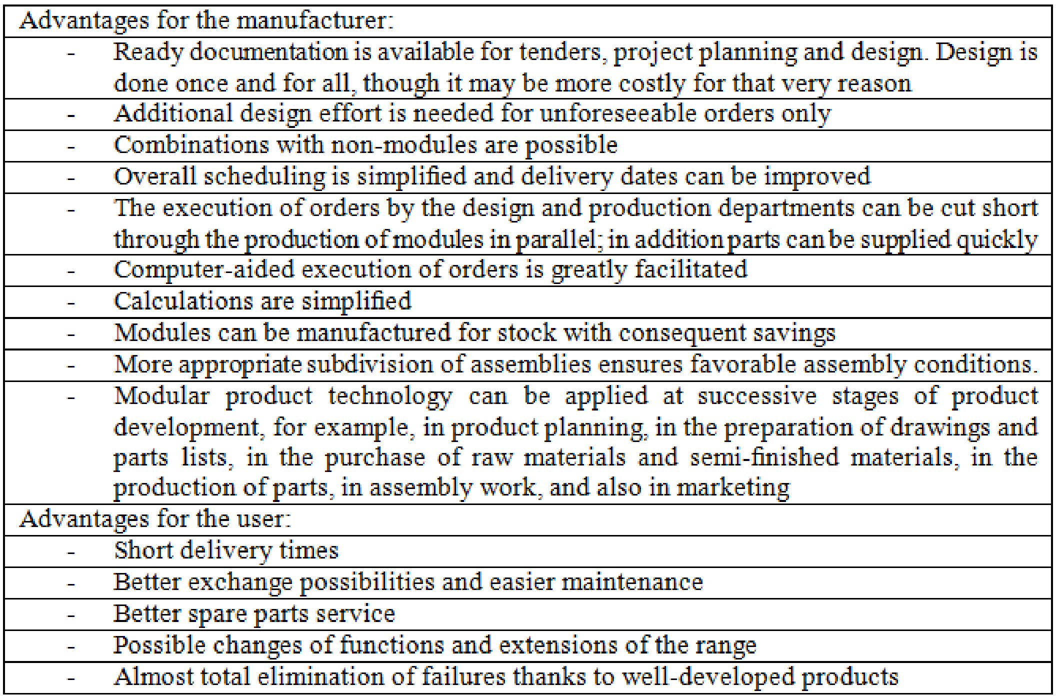
2015). Two of them – Modular Function Deployment (MFD) and Brownfield Process (BfP), their behavior and suitability into the case company context of shipbuilding industry have explored in more details by Graf in his Master’s Thesis (see Graf 2016).

MFD has been developed in 1998 by Gunnar Erixon in his dissertation of Modular Function Deployment - A method for Product Modularisation. It is a systematic method and procedure for developing new modular products as well as evaluating modular concepts (Erixon 1998). According to Ericsson & Erixon (1999, p. 29) the aim of MFD process is to find the optimal modular product design with specified company needs. The Brownfield Process is more recently published method as the latest version of BfP is published in 2015 by Pakkanen in his dissertation of Brownfield Process: A Method for the Rationalisation of Existing Product Variety towards a Modular Product Family (see Pakkanen 2015). However, initially the BfP was published in a research study in 2011 (see Lehtonen et al. 2011) where Pakkanen was also participated in the research study. While the MFD is more suitable for designing totally new product architecture, the BfP is more useful for already existing product designs with the aim of rationalizing them towards a modular product family by reducing complexity and enabling variety within a product assortment (Pakkanen 2015).

3.3.3 Motivating modularization

Modularization offers several advantages for both the manufacturer and the user of a product while at the same time it includes some disadvantages and cause limitations for operations. Some effects of modularity have already been touched briefly on the previous chapters. Furthermore, effects of standardization reflect also to the effects of modularity. As discussed already earlier, there are challenges and difficulties to implement product design modularity into the complex capital goods industry. Hellström (2014) explains that challenges to increase product design modularity form mainly because of unstable and discontinuous demand, low production volumes as well as long life cycle and increasing amount of service content within complex capital goods. Despite the implementation challenges, modularity brings also advantages for the project businesses similarly it does for other industries. According to Ericsson & Erixon (1999, p. xi) manufacturing companies achieve advantages such as shortened developmental lead times, improved managing of high degree of customization and reinforced product identity. Pahl et al. (2007, p. 508-509) have explored extensively advantages from both the manufacturer and the user point of views (see table 5).

Table 5. Advantages of modularity (Pahl et al. 2007, p. 508-509)

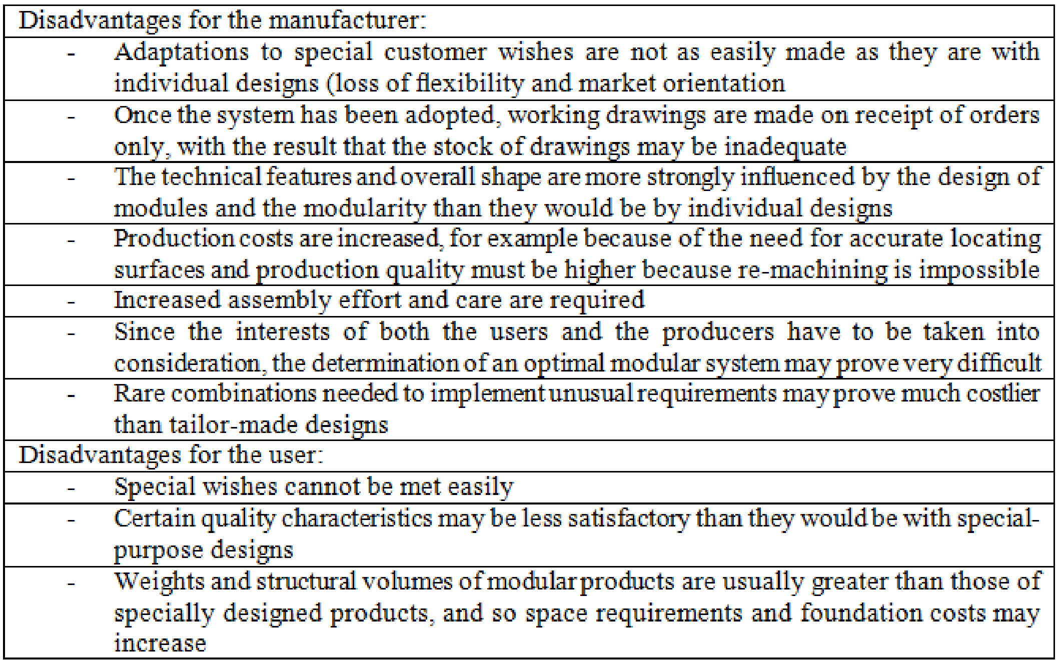


Advantages for the manufacturer:
- Ready documentation is available for tenders, project planning and design. Design is done once and for all, though it may be more costly for that very reason
- Additional design effort is needed for unforeseeable orders only
- Combinations with non-modules are possible
- Overall scheduling is simplified and delivery dates can 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 subdivision of assemblies ensures favorable 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
- Almost total elimination of failures thanks to well-developed products

Pahl et al. (2007, p. 509) highlight the wide influencing area of positive effects to cover almost all areas of manufacturing company. As can be noted from the previous table, positive effects consist mainly of features such as decreased amount of workload or fastened and simplified completion of tasks. Positive effects influence also positively in terms of costs by decreasing for example overhead costs such as administrative personnel costs (Pahl et al. 2007, p. 509).

Pahl et al. (2007, p. 509-510) have also identified comprehensive list of disadvantages and limitations that modularity brings (see table 6). As can be seen from the table, modular systems are often more limited and inflexible in relation to specific customer requirements. Generally, structures of modular systems might be stronger which raise the overall weight of the product. Pahl et al. (2007, p. 510) explain the phenomenon by arguing that greater structures and volumes of modules do not entail so significant cost savings in production and materials costs. However, they state that remarkable positive cost effects can be achieved if the modular product is designed in a way its structure is developed to be more cost-effective from every point of views compared to specially designed product.

Table 6. Disadvantages of modularity (Pahl et al. 2007, p. 509)



Disadvantages for the manufacturer:	
-	Adaptations to special customer 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
-	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 and production quality must be higher because re-machining is impossible
-	Increased assembly effort and care are required
-	Since the interests of both the users and the producers 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

3.4 Modularity and task management

This chapter adds discussion to modularity from the internal co-ordination and network handling point of views concentrating on topics of concurrent engineering, outsourcing strategies and knowledge sharing. In the case company context of shipbuilding, the operating environment includes a great amount of actors from inside the company and outside from the network taking a part in project execution. It becomes crucial to be able to manage own and outsourced processes as well as information, know-how and skills related to them. Especially, in the case company context and modularization purposes, comprehension of these issues within and across firm boundaries is significant and will be inevitably faced. Parallel manufacturing is often related to modules and it might be done outside of company's borders, which requires sufficient information sharing. Managing of information sharing between the yard and network is crucial especially in longer periods of time due to the confidential nature of know-how. Carelessly managed it might have an effect for moving the focus of expertise.

3.4.1 Concurrent engineering

The concept of concurrent engineering (CE) is closely related to modularity and appears especially in the tasks sharing and design principles of modular products. In the environment of manufacturing company, successful design activities of modular products require concurrent engineering way of operating. Stjepandić et al. discuss very comprehensively the concept in their book of Concurrent Engineering in the 21st Century. They (Stjepandić et al. 2015, p. 1) highlight the importance of CE by emphasizing it as way of thinking and describing it as a prerequisite in today working environment of projects, supply chains and networks which are characterized by complex and dynamic features. Stjepandić et al. (2015, p. 1-2) define concurrent engineering as *"a comprehensive, systematic approach to the integrated, concurrent design and development of complex products and their related processes, including marketing, manufacturing, logistics, sales, customer support, and disposal."*

Whitney (2004, p. 317) emphasizes the main feature of concurrent engineering to integrate wide variety of people to participate into the design process in order to get the demand satisfied and requirements balanced that arise from different actors such as from marketing, financial, engineering, manufacturing, assembly, after-market service, upgrading and recycling. Although above presented definition might lead to the idea of a ready method or a tool how to implement concurrent engineering for a business, Stjepandić et al. (2015, p. 2) and Whitney (2004, p. 317-318) still highlight that there exists not any workflow to accomplish the way of concurrent engineering in company's procedures.

Despite the lack of such workflow, the emphasis is on the team approach in order to create a multidisciplinary group of specialists who is able to consider wide variety of design factors at different product life cycle stages (Whitney 2004, p. 318). Stjepandić et al. (2015, p. 2) emphasize concurrent engineering to require continual communication between motivated and cooperative stakeholders supported by advanced IC technologies. Whitney (2004, p. 318) highlights that no one designer cannot have alone all the required knowledge needed by a comprehensive design work. Without a proper team work that is started at early stages of a design process, it is generally known that problems and conflicts will arise in a complex manufacturing environment.

Stjepandić et al. (2015, p. 390) add a discussion to the concept of concurrent engineering in relation to the context of modularity. They encourage combine technical aspects of modularity with business aspects and examine modularity through a qualitative and a quantitative point of views (see figure 17).

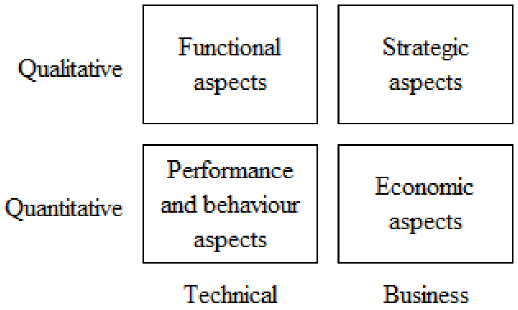


Figure 17. Viewpoints of concurrent engineering in modularity (adapted from Stjepandić et al. 2015, p. 391)

From the technical point of view qualitative aspects consider functional aspects of the modularity and quantitative aspects consider performance and behavioral aspects of the modularity. Correspondingly, from the business point of view qualitative aspects include considerations of strategic issues and quantitative aspects handle economic issues of the modularity.

Stjepandić et al. (2015, p. 390-391) discuss the main purposes of modularity in both technical and business divisions. From technical point of view, they discuss component commonality and component modularity. Component commonality considers usability of a certain component across several products. It provides possibilities to decrease internal variety in operations while increasing their external variety for customer purposes. With component modularity they mean the same thoughts as considered already earlier i.e. connections between components that can be explored and measured with three axioms: How components share direct interfaces with adjacent components? How design interfaces may propagate to nonadjacent components in the product? How components may act as bridges among other components through their interfaces?

From the business point of view modularity aim to make complexity manageable, aim to enable parallel work and aim to accommodate future uncertainty, according to Stjepandić et al. (2015, p. 391). They discuss effects that modularity has to the financial and organizational structures of an industry with three axioms. Firstly, they consider modularity as a financial force that has an ability to make changes to industrial structures. Secondly, they emphasize to explore the value and costs affected by a modular product design. Thirdly, they emphasize to explore the corresponding effects for organizations and the risk modularity cause for particular enterprises. Economical influences of modularity will be investigated in more details in the latter part of the thesis when exploring modular case examples and their cost effects for the case company.

3.4.2 Outsourcing strategies

Campagnolo & Camuffo (2010) discuss the relationship between product modularity and company's outsourcing strategies. They have explored current literature in that field during recent decades and explain that there exist authors suggesting that there is connection between product modularity and outsourcing strategies of their production while some authors have opposite considerations (see e.g. Galvin & Morkel 2001, Sako 2003, Fixson 2005, Frigant & Talbot 2005, Prencipe et al. 2003, Brusoni & Prencipe 2001, Pil & Cohen 2006).

Sako (2003, p. 237) defines outsourcing as *"the reallocation of tasks from within an organization unit to another, normally separated by ownership"*. She discusses modules outsourcing in a way the original equipment manufacturer (OEM) considers outsource either design and development or production and assembly, or both of them. For simplifying the quite complex overall picture of modules outsourcing, Sako's presentation assumes there to be only one set of tasks: design only, production only or packages of design and production (Sako 2003, p. 239). In such situation (see figure 18), there exist three different paths for modules outsourcing (Sako 2003, p. 239-240; see also Campagnolo & Camuffo 2010). The initial starting point is in the upper left corner where a vertically integrated company has an integral product architecture manufactured in-house with the aim to modularize its architecture and outsource its manufacturing.

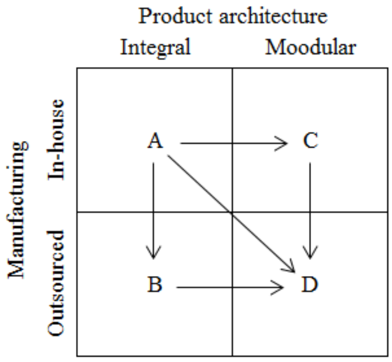


Figure 18. Outsourcing paths (adapted from Campagnolo & Camuffo 2010)

The first path (ACD) starts with an urge to at first transform the existing integral product architecture to modular architecture that is still manufactured in-house. After that the module's manufacturing will be outsourced. In this trajectory Sako (2003, p. 239) discusses modular architecture to be adopted first because it is supposed to improve OEM's performance and solve complex design problems. Outsourcing of modules manufacturing she explain to happen over the time. Campagnolo & Camuffo (2010) identify this path to obviously occur in a case of newly growing industry without existence of a dominant modular design.

The second path (ABD) starts with outsourcing non-modular components followed by transforming the integral product architecture towards modular one. Sako (2003, p. 239) explains the decision to outsource manufacturing to be the primary will instead of modularization in this trajectory. Afterwards, transformation towards modular product architecture depends either on the manufacturer's desire to develop it or the pressure from the OEM. However, modularization might take time to happen. Mature industries are probable examples that will most likely to follow this path (Campagnolo & Camuffo 2010).

The third path (AD) does simultaneously both changes i.e. implements modular product architecture and outsources its manufacturing. Sako (2003, p. 239) explains this trajectory to be possible only in a case there exists already appropriate and capable module suppliers in the market. Campagnolo & Camuffo (2010) add another viewpoint of a company that has not committed to arisen modular design and it is therefore forced to re-organize its strategy and develop its existing non-modular product architectures in order to stay competitive.

3.4.3 Knowledge sharing

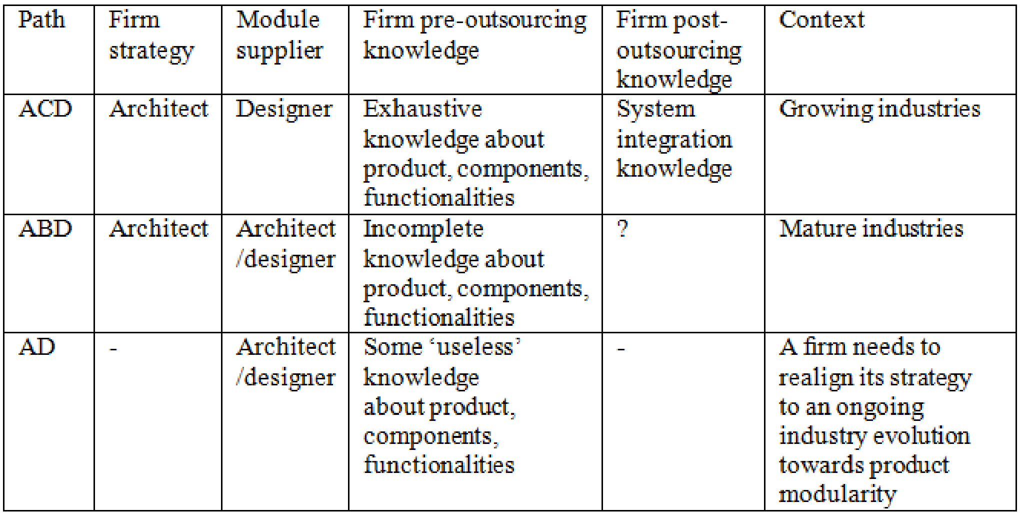
As stated above, there exist different reasons to choose a certain path and naturally influences after the path choice which together drive a company towards a certain path. Furthermore, there exist some dangers in knowledge sharing in relation to presented paths because outsourcing of company’s operations requires always a distribution of capabilities and knowledge between the OEM and the supplier from the network. Information sharing outside of firm boundaries is a truly relevant topic for considerations right in the case company within modularization purposes.

Sako (2003, p. 239-240) and Campagnolo & Camuffo (2010) highlight noteworthy considerations in relation to the topic. In a case of the first path, Sako (2003, p. 239) argues that the need for knowledge sharing between the OEM and the supplier is very limited because the OEM is able to keep majority of module design and architectural knowledge in-house. Campagnolo & Camuffo (2010) describe the OEM as an architect that has a determinative position in relation to the module supplier that they call a designer who is strictly committed to follow the design rules set by the OEM. All the know-how and capabilities to develop and maintain product architecture as well as capability to systems integration are hold inside the company, which create it possible to reverse outsourcing decision.

The second and the third path require more information sharing between authors. Especially in a case of the third path, Sako (2003, p. 239-240) emphasizes significant danger for losing in-house capabilities and control to the module supplier. Supplier might slowly get an opportunity for determinative position in a case where the know-how has like totally moved outside of the OEM’s boundaries. Campagnolo & Camuffo (2010) state in this case that company’s competitiveness should be built on other sections of value chain, because of lost capability to control a product and missed abilities of system integration. They illustrate module supplier to act as an architect and designer in order to design, engineer and produce a module.

See table 7 to view a summary of paths, positions of OEM and supplier, knowledge before and after outsourcing as well as appropriate industry examples. According to Sako (2003, p. 240) a company will achieve an overall improvement in supply chain operations due to modularity if modules are produced in-house or acquired as ready solutions from the suppliers from the network. On the contrary, Sako (2003, p. 240) explains that outsourced module manufacturing without a company's strict control of module solutions might have an effect to increase the complexity and make the operation more expensive compared to in-house manufactured modules.

Table 7. Summary of outsourcing paths (Campagnolo & Camuffo 2010)



Path	Firm strategy	Module supplier	Firm pre-outsourcing knowledge	Firm post-outsourcing knowledge	Context
ACD	Architect	Designer	Exhaustive knowledge about product, components, functionalities	System integration knowledge	Growing industries
ABD	Architect	Architect /designer	Incomplete knowledge about product, components, functionalities	?	Mature industries
AD	-	Architect /designer	Some 'useless' knowledge about product, components, functionalities	-	A firm needs to realign its strategy to an ongoing industry evolution towards product modularity

4 COST MANAGEMENT

Pahl et al. (2007, p. 535) discuss the importance to identify cost factors at the very beginning stage of a product life cycle, already at the early stages of a design work. They emphasize that the majority of total costs of a product have already been committed at the design phase. At the later stages of a product life cycle such as at manufacturing or assembly stages, there are fewer opportunities to reduce total costs. Consequently, one can be said that more emphasis spent to the product design together with intensive concurrent engineering way of working will pay itself back at the later stages with remarkable cost savings. This chapter provides an overview to different cost categories, explains the structure of manufacturing cost formation and introduces usable cost accounting method.

4.1 Categorization of costs

Costs can be divided into different categories in a couple of different ways. According to Pahl et al. (2007, p. 535) the total cost of producing a product consists of two types of costs: **direct costs** and **indirect costs**. The latter ones are generally known also as **overhead costs**. According to Neilimo & Uusi-Rauva (2012, p. 58) this kind of categorization is used especially in a product-specific accounting where direct costs can be allocated directly at a certain stage of a production to a certain product or a product group because there exists obvious causality between them. Indirect costs behave differently so they cannot be allocated directly to a specific cost carrier. Pahl et al. (2007, p. 535) explain direct costs include costs such as material and labor costs whereas indirect costs include for example warehouse running costs and lightning costs of facilities.

Neilimo & Uusirauva (2012, p. 56-58) present also two other common ways to categorize costs (see figure 19). According to them, the most common way to classify costs is to divide them into **variable costs** and **fixed costs**. Generally, categorization of costs either to variable costs or fixed costs depends on an operating rate of the company. Variable costs change at the same time when the operating rate of the company changes, whereas fixed costs are not dependent on the operating rate of the company. Fixed costs are tied to changes in the capacity of the company and thus they depend on changes of potential factors. Pahl et al. (2007, p. 535) discuss variable and fixed costs from the amount of ordered products point of view. According to them, variable costs increase with higher turnover, whereas fixed costs will stay constant at the same time. Neilimo & Uusi-Rauva (2012, p. 58) argue that direct costs consist mainly of variable costs and indirect costs consist of fixed costs.

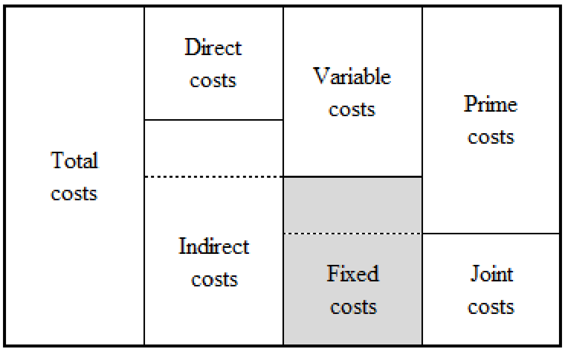


Figure 19. Cost categories (adapted from Neilimo & Uusi-Rauva 2012, p. 55)

Neilimo & Uusi-Rauva (2012, p. 56-57) have faced ambiguities in dividing of costs into variable and fixed costs. They highlight that division depends on a certain company context and a length of observation period. If the observation period is enough long, all the costs will vary to some extent. On the other hand, in a short time frame, majority of costs can be seen as fixed costs. Variable costs consist mainly of costs of consumable raw materials, purchased parts and semi-finished products, production labor costs, production work done by subcontractors, energy consumption costs as well as maintenance costs of machines, equipment and tools. Fixed costs include costs such as management salaries, interest on tied capital of machines and equipment, depreciations, rent of space as well as heating and cleaning costs of facilities. (Neilimo & Uusi-Rauva 2012, p. 56; Pahl et al. 2007, p. 535)

Fixed costs can be further divided into two sub-categories: **fixed down-time costs** and **fixed standby costs**. Fixed down-time costs arise although the production unit is not in use. They include costs such as leasing fees of machines, rents of facilities and depreciations. Fixed standby costs arise because of readiness to start the production at any time. They include costs such as heating costs of facilities and occupation of the production unit. (Neilimo & Uusi-Rauva 2012, p. 57)

The third way to categorize total costs is to divide them into **prime costs** and **joint costs**. Prime costs are affected by a matching principle and the causality between a certain cost and the product can be recognized. Prime costs include costs that arise when a product is produced, or a project completed. They will not arise if the product is not produced or a project is not carried out. Joint costs are costs that will arise even though the product is not produced, or a project is not carried out. Thus, prime costs refer to direct costs and variable costs and joint costs refer to indirect costs and fixed costs. (Neilimo & Uusi-Rauva 2012, p. 59)

4.2 Formation of manufacturing costs

Basically, manufacturing costs consist of variable and fixed costs. According to Pahl et al. (2007, p. 535) manufacturing costs form mainly from two sections: from the total costs of materials and the total costs of production (see figure 20). From the figure below can be seen that both material costs and production costs are further divided into direct costs and indirect costs. Direct material costs form mainly of used materials and bought-out parts whereas indirect material costs include costs of supportive functions such as material storage costs. Direct production costs include production labor costs which can be basically counted from committed production times multiplied by appropriate labor cost factors.

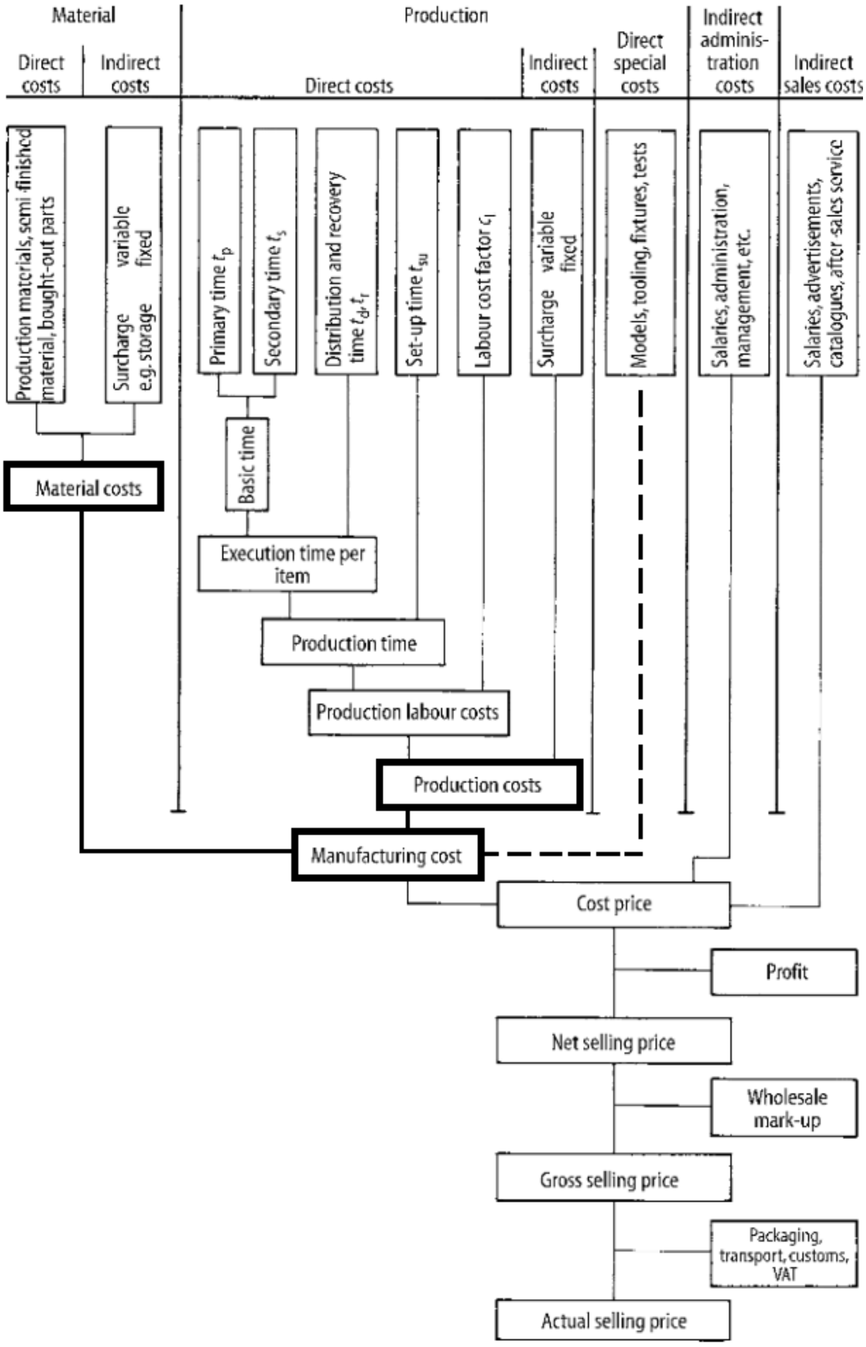


Figure 20. Overall manufacturing costs (adapted from Pahl et al. 2007, p. 536)

Pahl et al. (2007, p. 535) explain that there exist also some avoidable additional manufacturing costs due to the nature of production such as costs from production tooling and fixtures as well as required tests and created models if they can be allocated straight to a certain product. Indirect production costs are those supportive overhead costs of production which cannot directly be allocated to the specific product. On the right side of the figure can be seen other overhead costs such as indirect administration and sales cost which are excluded from the manufacturing costs. As can be noted, they have effects to the cost price of a product but not directly to share of manufacturing costs of it.

Pahl et al. (2007, p. 535) emphasize designers' ability to affect the variable part of costs from the amount of overall manufacturing costs with their design decisions. They explain such decisions to consist of for example choices related to material types, production times, batch sizes, production processes and assembly methods. Fixed costs cannot be affected in a similar way it is possible to do for variable costs. Manufacturing costs are in the interest of this thesis in the following part when exploring modular case examples and measuring their cost effects.

4.3 Activity-based costing

Activity based costing (ABC) is one of the most used cost accounting method. ABC has evolved alongside a traditional cost accounting method and gained lots of interest among companies' management. It has also been widely used as a calculation tool for a strategic management. Activity-based costing offers several advantages for companies such as it helps better to understand the relationship between resource consumption and the price of product, the cost behavior in complex business environment as well as it provides possibilities to concentrate on process development. (Alhola 2016, p. 8-9)

Activity-based costing is often compared to the traditional cost accounting in order to describe its nature and make a difference between methods. In traditional cost accounting, the main target of review is a product whereas in activity-based costing it is activities of a company (Neilimo & Uusi-Rauva 2012, p.145). According to Alhola (2016, p. 8) the main difference between methods is the principle in allocation of costs. He explains that in ABC all costs, both direct and indirect costs, are allocated based on different activities and the matching principle whereas in the traditional cost accounting overhead costs are allocated to the calculation target (e.g. product) in proportion of direct costs. Neilimo & Uusi-Rauva (2012, p. 144) give a criticism to the traditional cost accounting especially due to the lack of existence of matching principle in allocation of overhead costs.

According to Neilimo & Uusi-Rauva (2012, p. 145) principles of activity-based costing are based on three main concepts: **costs**, **activities** and **products** (see figure 21). They explain that the idea of cost allocation in ABC starts from activities. Company needs activities such as R&D, procurement, manufacturing or sales, and performances produced by them in order to manufacture a product. Activities further require resources such as employees, materials, machinery or facilities which naturally cause costs for the company. Costs are reduced from returns which are earned from the customers when they buy products. The remaining difference between returns and costs are the result of the company. In activity-based costing, costs are first allocated to resources and further to activities in proportion to usage of resources. From activities costs are allocated to products or other calculation targets in proportion to the actual consumption by each. (Neilimo & Uusi-Rauva 2012, p. 145)

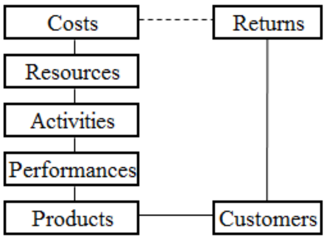


Figure 21. Activity-based costing model (Neilimo & Uusi-Rauva 2012 p. 145)

In the case company context activity-based costing might be a worthwhile method to improve the consciousness of cost behavior and the understanding of cost formation during the project execution. There have been examples of areas in the past projects where it has appeared unawareness in classification of realized costs into different departments. As it was discussed above, activity-based costing brings several advantages and improves the understanding of cost formation, especially in a complex environment. Neilimo & Uusi-Rauva (2012, p. 143) encourage that the information achieved by activity-based costing should be exploited actively to the cost management in order to systematically improve the competitiveness of a company. One can imagine that activity-based costing might be a good method to improve the managing of cost formation of such examples. As discussed ABC provides a comprehensive understanding of overhead costs and improve the cost allocation. Although the use of activity-based costing might require changes in current methods and require more effort, in a long term it will improve the cost management in a complex environment and provide more accurate results.

5 RESEARCH FOR THE COST EFFECTS OF MODULES

This chapter starts an empirical part of the thesis and concentrates on the research about the cost effects of modularity utilization from the selected module case examples point of views. The research is done for two different module assemblies which are deliberately different from each other making the research interesting and quite different as well as to respond for the case company's desire. Before the detailed research descriptions of case examples are presented, more detailed explanation of the case company's processes should be offered in order for being able to understand consistent order of shipbuilding process tasks.

5.1 Shipbuilding process overview

According to Andritsos & Perez-Prat (2000) shipbuilding process consists basically of two major processes: information and production processes. They explain the most important parts of the information process to consist of design of a ship and planning and coordinating activities of the production processes. These information related activities are performed by the departments of sales, classification, basic design, detail design, procurement and work planning in the case company context. They make all the necessary information related work before the production of a ship can start. The shipbuilding production process (see figure 22) is further divided into two main categories including hull production and outfitting work. The following figure complies also with the shipbuilding process overview in Meyer Turku and thus, it provides a good overview of their major processes as well.

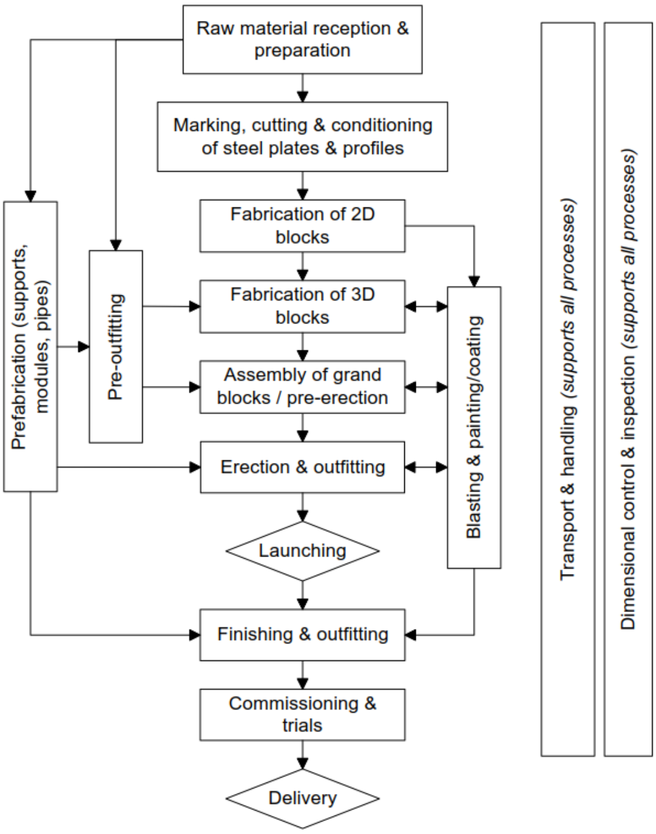


Figure 22. Shipbuilding production process flow (Andritsos & Perez-Prat 2000)

The hull production process means basically transforming of steel plates to the hull structures of a ship. As can be seen from the figure above, the process starts from *part fabrication* stage including tasks such as marking, cutting and conditioning of steel plates and profiles. The following stages are fabrication of 2D blocks and further 3D blocks which are known as *sub-block assembly* and *block assembly* stages in the case company context. After the block assembly the following stage is to assemble completed blocks further to grand blocks *(grand block assembly)* which will be then transferred to the dry dock and assembled together to form the ship hull itself *(hull assembly)*.

Outfitting work will be done actively in parallel with these stages of hull production. Outfitting work starts mainly at the block assembly phase and continues until the ship is ready for the delivery. Very first tasks of outfitting work include duties such as pipe, duct and insulation installation work and further installation of cabins, surface materials and so on. Outfitting work includes mainly all production tasks, but the steel work related to the hull production of a ship. When the erection of a ship hull is done, and the outfitting work is at required level, the ship will be launched from the dry dock to the outfitting pier. The following main steps after floating out are continuing of outfitting work, commissioning of ship's systems and sea trials before the ship delivery to the ship owner. Figure 23 below gives a simplified description of the shipbuilding project.

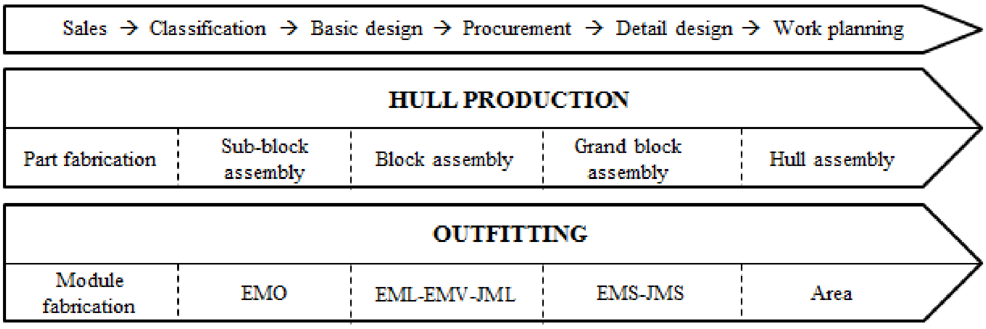
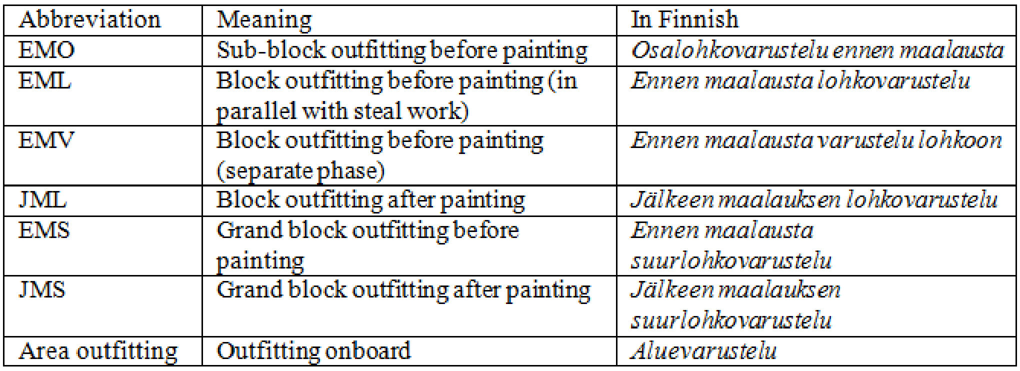


Figure 23. Shipbuilding project overview

As can be seen from the figure, outfitting work is divided into different sub categories in relation to the process stages of hull production. Timing of a block or grand block painting has effects to the determination of outfitting stages. Furthermore, another remarkable milestone in block fabrication and outfitting processes is a turnaround point of the block. Blocks are turned around after the EMV-phase. Before that blocks are upside down due to the features of their manufacturing process and ability to do down-hand outfitting work for blocks' ceilings. See table 8 to view explanations for the abbreviations of the outfitting phases. Abbreviations come from Finnish words with the principles that are presented in the table.

Table 8. Outfitting work stages



Abbreviation	Meaning	In Finnish
EMO	Sub-block outfitting before painting	*Osalohkovarustelu ennen maalausta*
EML	Block outfitting before painting (in parallel with steal work)	*Ennen maalausta lohkovarustelu*
EMV	Block outfitting before painting (separate phase)	*Ennen maalausta varustelu lohkoon*
JML	Block outfitting after painting	*Jälkeen maalauksen lohkovarustelu*
EMS	Grand block outfitting before painting	*Ennen maalausta suurlohkovarustelu*
JMS	Grand block outfitting after painting	*Jälkeen maalauksen suurlohkovarustelu*
Area outfitting	Outfitting onboard	*Aluevarustelu*

During the last years, emphasis on the production process of modern cruise vessels has shifted towards extensive outfitting work. Andritsos & Perez-Prat (2000) discuss the phenomenon and explain that increased complexity of vessels increases remarkably the share of outfitting work meanwhile it decreases the share of steel work. They expect outfitting work to cover up to 80 % of the total costs of work while steel work covers only the rest 20 % of the total amount. They highlight also significance of material costs related to ship pricing as well as costs of planning and management which create a large share of the total project costs.

5.2 Introduction to the research scope

Meyer Turku can be called as an assembly yard that is defined by Hellström (2014) as *"a model in which the shipyard outsources the responsibilities for larger systems and areas in the ship to turnkey suppliers"*. In the assembly yard model Meyer Turku provides facilities for its subcontractors and concentrates mainly on hull production of the ship and managing the project itself while the outfitting work is mainly done by subcontractors and further by their subcontractors. Hellström (2014) explains public spaces such as kitchens, theaters and cabin areas as well as systems such as air-condition, lifts or engine room to be typical outfitting work areas which are outsourced for turnkey (TK) suppliers. According to Andritsos & Perez-Prat (2000) the use of turnkey suppliers has increased during the last decades due to the nature of highly varying workload at different stages and the need for highly skilled persons for complex duties.

The usage of turnkey suppliers has a close relation to the earlier discussed topic of task and know-how sharing between the yard and its network. In some cases, at the yard, one can notice consequences for example in terms of lack of the detailed knowledge regarding on specific work tasks and their durations performed by turnkey suppliers or their subcontractors. The phenomenon does not only occur in a case of external actors but also in production data controlling and storing of work performed by yard’s own work force. Inadequate knowledge of processes might have inevitable effects e.g. to the success of accurate planning or process development activities and further effects will emerge also in terms of costs.

Outfitting work is preferable to do at as early phases of the shipbuilding process as possible. Andritsos & Perez-Prat (2000) discuss the trend of pre-outfitting blocks and grand blocks as much as possible before the erection of a ship hull. This has also been recognized in the case company in order to increase the amount of completed outfitting work at early phases. Andritsos & Perez-Prat (2000) explain that the work done in early phases is much more efficient to perform than it is done in the ship hull, providing also lots of advantages. They offer examples of moving the outfitting work from inside the vessel to more favorable places such as to workshops with advantages of much more optimal working conditions and easier material handling. Due to the better working conditions, one man-hour of outfitting work done in a workshop is equivalent to about two man-hours at the dock (Andritsos & Perez-Prat 2000).

Other estimates of required workloads at different production stages have been offered by SPAR (2011). Their estimations are based on the study done in Japanese yard arguing that one man-hour of work in a workshop corresponds to three man-hours on the dock and even five man-hours on the ship. SPAR (2011) offers also a comparison based on committed primary labor costs at parts manufacturing, on-unit assembly, on-block assembly and on-board assembly stages (see figure 24). As the figure shows there is a huge difference in terms of costs between different stages. Perceptions by SPAR (2011) argue with the same arguments provided by Andritsos & Perez-Prat (2000) that the outfitting works done in earlier phases offer significant cost saving for the yard.

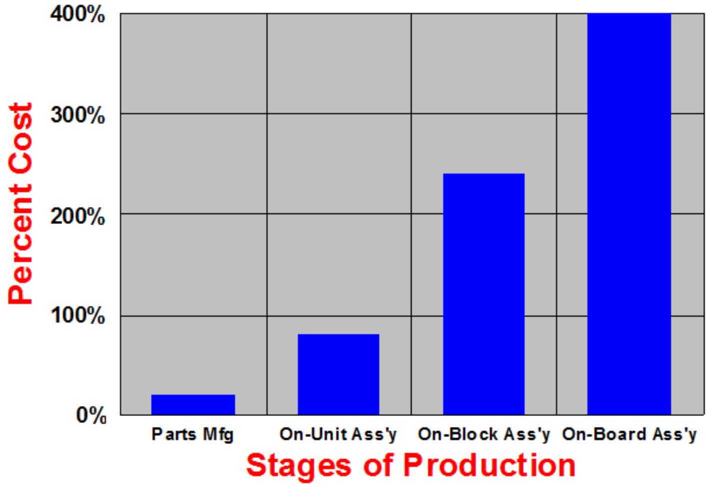


Figure 24. Primary labor costs distribution (SPAR 2011)

The figure 25 below illustrates formation of costs in relation to shipbuilding processes stages and the relatively completed workload from the project’s total amount. As the figure shows, the majority i.e. approximately over 70 % of the project total costs are locked at the end of the basic design phase. At the same time the amount of completed workload of the whole project is only just beginning. The 70 % share of locked costs is equivalent to only 3 % of the completed total workload of the whole project.

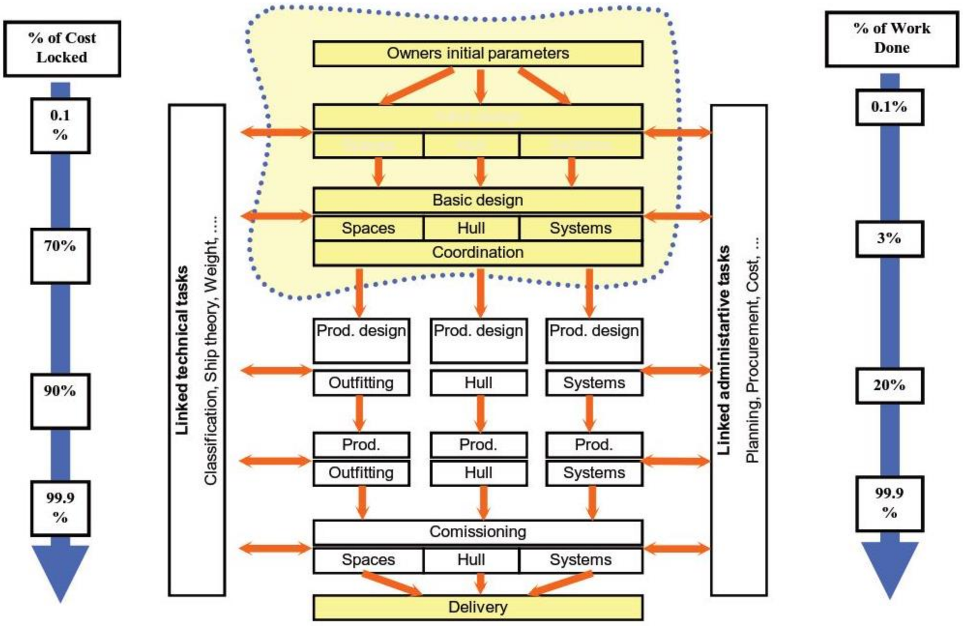


Figure 25. Committed costs in relation to project execution

The previous figure makes sense with the above presented notion of the relationship between early design decisions and their remarkable cost effects to the total project costs. As can be seen from the figure, at the beginning of production almost all the total costs are known. The figure states that roughly 90 % of the total costs are locked at that time. However, it accounts only for 20 % of the completed work of the whole project. The rest of the project execution does not create remarkable additional costs in relation to planned project costs although the major share of project workload arise since the production begins.

5.3 Corridor piping module

Corridor piping module is under review as a first modular case example of this thesis. Although the corridor piping module itself is quite simple assembly, its effects have been much more remarkable because it has affected widely to several different departments over the shipbuilding process. The module usage has even affected to the hull structures of the ship, so the aim is to explore its cost effects extensively and diversely. Furthermore, the equivalent parallel point of comparison is also available for the corridor piping module which makes the comparison sensible and possible to realize in the scope of this study.

The main purpose of this study was to sort out the cost effects affected by the use of corridor piping module. In the study the module is compared to another used method to outfit pipes into the ship hull at the equivalent area in the same vessel. This non-module utilizing pipe outfitting work is called traditional method in this thesis. Before the study there were not clear evidences which are the total cost effects of using the module for the yard. It seemed to be clear from very beginning that there occur both advantages and disadvantages depending on the process stage under review. Mainly positive effects were discussed in the outfitting department but the effects to the hull production department seemed to be easily passed away. However, the clear understanding of the total cost effects was still lacking and inspired to do the comprehensive study covering all the relevant phases of the shipbuilding process.

5.3.1 Module description

The corridor piping module (see figure 26) has been developed in Meyer Turku couple of years ago and it is used in Mein Schiff ship series. Corridor piping module is used in passenger cabin areas of the vessel and it is placed horizontally on the ceiling of the corridor in such cabin areas. The module’s operating area covers approximately one third of passenger cabin areas between five decks (see appendix 1) while the rest of areas are covered with the traditional building method of pipes. The module consists of pipes that service specifically passenger cabins. Cable tray act as a module’s frame and pipes are attached to the cable tray. The module includes potable water pipes, water pipes for cabin’s air conditioning (AC) cooling system and hi-fog pipes for fire emergency purposes depending on which deck is under review.

Figure 26. Corridor piping module

The corridor piping module has been developed in order to intensify block outfitting work as well as to improve quality issues of pipe installation work. The module has decreased the amount of required workload at outfitting phases and made it possible to shift workload from site to the factory with significant better industrial working conditions. Consequently, the module fabrication is done outside the vessel and the yard and it has enabled to do parallel work. However, there occur also disadvantages due to the module usage such as growing amount of additional work at some phases. The following chapters explore and identify the effects of module usage and measure them in terms of costs.

5.3.2 Clarifying differences

The research scope about the cost effects of the module usage covers almost the whole shipbuilding process and the module’s life cycle. The research follows mainly the chronological order of the shipbuilding process. Design functions as well as hull production and outfitting functions were studied carefully through in relation to the module usage and the traditional building method of pipes. The very first stage (sales) and the last stage after delivering the vessel (warranty) have been excluded from the study (see figure 27). Furthermore, development costs of the module itself are also excluded from the study.

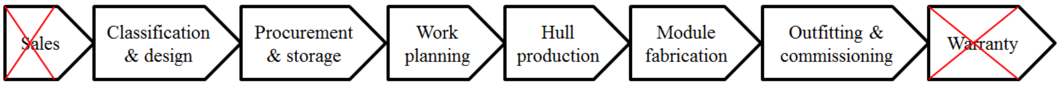


Figure 27. Research scope of the first case study

Each process stage was explored step by step and differences between the module usage and the traditional building method of pipes were discovered and analyzed. Activity-based costing method was utilized in the cost calculations where the main focus was on direct (variable) costs while indirect (fixed) costs were excluded from the survey because they were supposed to remain the same regarding on the study. The survey concentrated mainly on the required workload and differences within it at different process stages and made the comparison from that point of view. It proved to be enough extensive and efficient way to perform the study in order to get adequate results in relation to the nature of the study and the scope of the thesis. The main features of the study will be presented here in the following paragraphs. Due to the sensitive and confidential nature of some detailed material, they are placed on the appendixes hold by the case company.

Design, planning and procurement

Department of classification and hull basic design faced the first effects of the module usage. Effects were occurred because the module was designed in a way that the traditionally used straight T-bars need to be lowered in the blocks of module’s operating area (see figure 28). Lowering of T-bars made it possible to use the module in a way it can only be dropped and attached to the lowering of T-bars at the block outfitting stage when the blocks are still upside down (see figure 26 and appendixes 2-3). Traditionally, pipes are installed throw the lighting holes of the T-bars in the passenger cabin areas (see appendix 4). The requirement to lower T-bars included wide range of tasks and caused a huge amount of additional design work for the classification and hull basic design department.

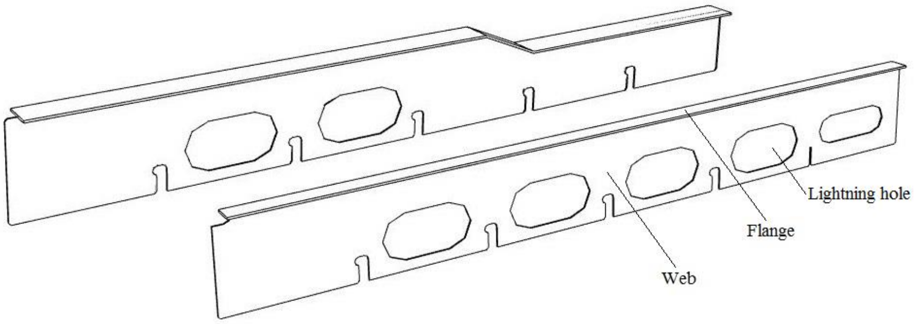


Figure 28. Lowered and traditional T-bar

At the following stage, department of hull detail design did not face measurable effects due to the module usage. Similarly, basic design department of heating, ventilation and air conditioning (HVAC) did not face differences compared to their traditional work. Next significant changes were observed in the workload of detail design department of HVAC. Traditionally, their workload consists of detailed routing, modelling and dimensioning of pipe lines based on the initial raw material produced by the basic design department of HVAC at the previous process stage. Due to the module usage they were also supposed to produce detailed and accurate manufacturing and installation drawings for each module in order the module's fabrication factory is able to manufacture modules and they can further be installed to the blocks. Chronologically progressed interior design and work planning were the next two departments the module might be influenced. However, it came to light that they did not meet any measurable differences in their work due to the module usage.

Material procurement and material storage functions are generally really essential areas of examination when considering modularity because they might face remarkable changes for example in suppliers of materials and in durations of material storage. Within this context the concept of total cost of ownership (TCO) is worth for further exploration. Basically, TCO considers offering's total costs throughout its lifecycle from acquiring to end-of-life management (Heilala et al. 2006). However, practices of material procurement and storage in this case study remained the same, so there were not any changes in them between the building methods and thus, no need to review them further. Piping materials are exactly the same used in both areas of comparison. Moreover, piping materials are normally stocked at the yard's storages, so their storage remained exactly the same as well.

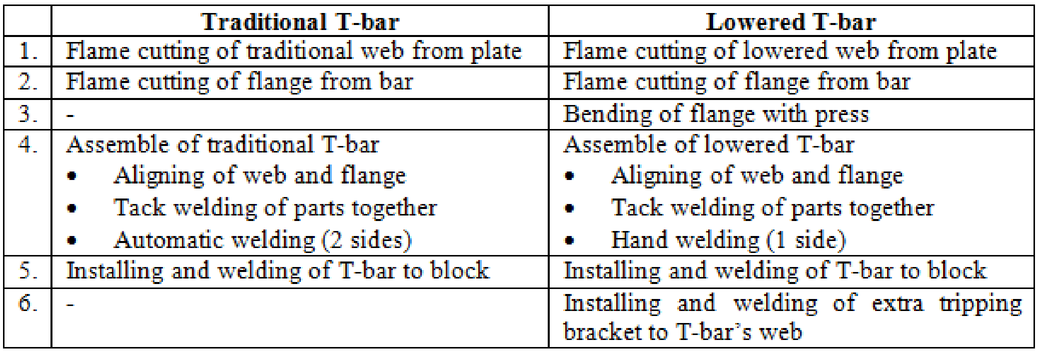
Hull production

After design, planning and procurement departments were explored the next step was to investigate about module's effects to hull production functions which began with part fabrication processes. As discussed already earlier, one significant change occurred in the structure of T-bars. The requirement to lower T-bars caused considerable changes for their manufacturing process. T-bars consist mainly of two parts: web and flange (see figure 28). Flame cutting of traditional or lowered web from plate or cutting of flanges from bar do not mean any differences between the processes. The first remarkable difference in hull production occurred in the following phase in manufacturing of lowered T-bars when the cut straight flange needs to be bended, being totally extra stage. The bend is done by a press with a principle to bend all the flanges needed by one block in a row. There occurred also challenges when the bended flange and lowered web were aligned at the next phase before tack welding and welding after that. Aligning of parts took often considerably more time, up to fourfold, compared to aligning of traditional straight parts.

The welding process in which the web and the flange are welded together was also highly different between lowered and traditional T-bars. Straight T-bars are welded with automatic welding machines whereas lowered T-bars need to be welded manually by hand. Hand welding is much slower due to manual hand work and the feature of automatic welding machine being able to weld both two sides at a time whereas hand welding is able to weld only one side at a time. Moreover, hand welding may cause quality challenges due to transformations during the hand welding process.

At the block assembly phase T-bars are installed and welded to blocks. There were not any differences in the welding processes of traditional or lowered T-bars to blocks because both of them are manually welded. The following difference occurred again in the case of lowered T-bars. They need one extra strengthening piece called a tripping bracket near the lowering in order to improve the strength of the lowered T-bar’s structure. Tripping brackets are installed and welded at the block assembly phase. After that the module usage did not affect to the following phases of hull production, neither to the grand block assembly nor to the hull assembly phases. Manufacturing process overviews of traditional and lowered T-bars are summarized in the table 9 below.

Table 9. Process overview of T-bars manufacturing



	Traditional T-bar	**Lowered T-bar**
1.	Flame cutting of traditional web from plate	Flame cutting of lowered web from plate
2.	Flame cutting of flange from bar	Flame cutting of flange from bar
3.	-	Bending of flange with press
4.	Assemble of traditional T-bar • Aligning of web and flange • Tack welding of parts together • Automatic welding (2 sides)	Assemble of lowered T-bar • Aligning of web and flange • Tack welding of parts together • Hand welding (1 side)
5.	Installing and welding of T-bar to block	Installing and welding of T-bar to block
6.	-	Installing and welding of extra tripping bracket to T-bar’s web

Material loss comparison was also investigated regarding on the part fabrication processes of hull production. In the T-bars manufacturing, the material loss forms mainly in flame cutting of webs from plates due to two characteristics: lightning holes and areas which form because of the lowered webs (see appendix 5). However, the investigation revealed that there were not significant and measurable differences of material loss between manufacturing of the lowered and the traditional T-bars. In addition, there occur also differences in material loss between different plates due to the various alternatives of nesting, so more detailed material loss inquiry was excluded from the study.

Module fabrication and pipe outfitting

Outfitting work is generally done in parallel with hull production process stages. As discussed earlier there are several phases of outfitting work based on the different phases of hull production. Outfitting activities under review of this study started at the EMV-phase where corridor piping modules are installed to blocks. At that time modules have already been prefabricated in the factory. Modules prefabrication is outsourced to the turnkey supplier of such cabin areas and even further to its subcontractor. The module supplier gets all the materials needed by the modules fabrication from the yard's storages. They transport materials from the yard to their facilities outside the yard and fabricate modules in there.

In traditionally built areas, there is not any prefabrication of pipes, but all the processing work of piping materials are done at the block outfitting phase which brings lots of extra work in there compared to the module usage. The survey revealed, that there exist also two different ways of traditional pipe outfitting depending on the turnkey supplier of such cabin area. One will centralize all pipes outfitting work at the EMV-phase, while another install considered pipes at the later outfitting phases, at the EMS- and JMS-phases after blocks have turned around and the grand block assembly is getting started. The latter mentioned traditional method covers approximately 70 % of those areas which are built in traditionally. In this study it was explored and compared to the module usage.

EMS- and JMS-phases of pipe outfitting work include also installation of fire prevention valves to the borders of fire zones in both building methods. In some grand blocks fire zone borders are in the middle of a certain block while sometimes they are at the border of adjacent grand blocks. In latter cases, the installation of fire prevention valves will be done at the area outfitting phase after the erection of a ship hull is done. However, these phases revealed to be similar in both areas of comparison, so there are not any differences between them.

Regarding on this study, the area outfitting phase included tasks such as coupling of pipe lines at the grand block borders, insulation work of pipes and the coupling of pipes from the corridor ceilings to the cabins that can be done after the cabin modules are lifted onboard and installed. Coupling work of pipe lines at the grand block borders and insulation work of pipes are similar in both areas of comparison so there did not occur any differences. Pipe insulation work is related only to AC cooling pipes and warm potable water pipes while cold potable water pipes and hi-fog pipes do not need insulations. The study revealed that differences occurred in coupling of pipes from the corridor ceilings to the cabins. There are so called maintenance triangles in front of every adjacent pair of cabins. Maintenance triangles include cabins' technical equipment and access to control and adjust their settings. Pipes are coupled from the corridor ceilings to the maintenance triangles in order to serve cabins' needs. Coupling of AC pipes in the modules' operating areas revealed to be a bit more challenging and time consuming to perform compared to the work done in the traditionally built areas.

In the modules' operating areas AC cooling pipe lines are located lower at the corridor ceilings in relation to their coupling points in the maintenance triangles which caused a need to install coupling pipes partly upwards. Due to this position there occurred a need to bled AC cooling systems after pipes installation. In these areas, bleeding pipes and valves need to be installed into each maintenance triangle. In traditionally built areas, AC cooling pipe lines are installed higher and closer to the corridor ceilings. Thus, they are located above the coupling points of maintenance triangles when coupling pipes are always installed to go downwards. In these traditionally built areas, the need to bleed AC cooling systems is much fewer and it is done only at the border of each fire zone.

Commissioning and warranty

The following phase, commissioning of pipe lines and systems was the last stage under review of this study. As it was discussed in the previous chapter, there occurred differences in coupling of AC cooling pipes and in commissioning of such systems after that. In the modules' operating areas commissioning takes more time and it is slower to perform due to the need to bleed AC cooling pipes at each maintenance triangle while in the traditionally built areas the need for bleeding is only at the borders of fire zones. After commissioning there are warranty issues which are out of the scope of this study but might perhaps include reclamations and repair requests of pipes. See figure 29 to view a description of pipe outfitting process overviews.

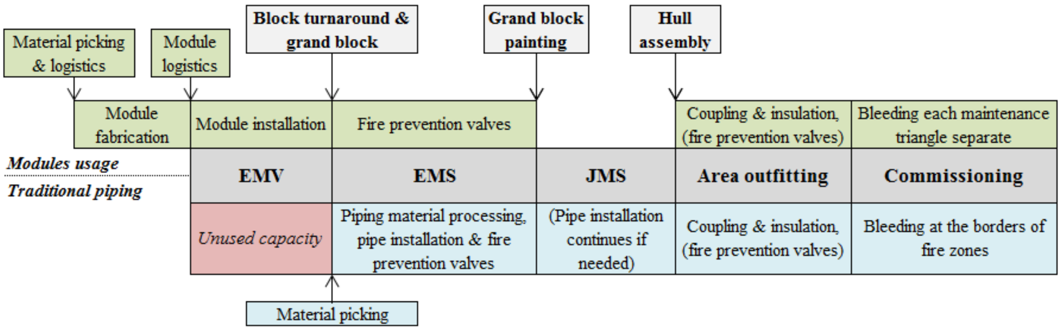


Figure 29. Process overview of pipe outfitting works

5.3.3 Results of the study

The usage of corridor piping module has affected widely to several departments and their functions, as the previous chapter stated. It is evident fact that the module usage has had both positive and negative effects in terms of costs. Table 10 below summarizes all the process stages and departments which are related to the piping of passenger cabin areas and were explored in this study. On the left side of the table are process stages and departments. In the middle of the table is a comparison between the areas of module usage and traditional piping method. From the right side of the table can be seen if the module usage has increased, decreased or it has not affected the committed costs of such department in relation to the traditional building method. See appendixes 6-8 for further information.

Table 10. Effects summation due to the module usage

Process stage and department		Building method		∑[h]
		Traditional	Module usage	
Sales	*Out of scope*			
Design and planning	Classification & hull basic design	-	Lowered T-bars	+
	Hull detail design	*Remain the same*		0
	HVAC basic design	*Remain the same*		0
	HVAC detail design	-	Detailed drawings	+
	Interior design	*Remain the same*		0
	Work planning	*Remain the same*		0
Procurement	Material procurement	*Remain the same*		0
	Material storage	*Remain the same*		0
Module fabrication	Logistics to factory	X	Piping materials	+
	Production	X	Modules fabrication	+
	Logistics to yard	X	Prefabricated modules	+
Hull production	Part fabrication	Traditional T-bars	Lowered T-bars	+
	Sub-block assembly	*Remain the same*		0
	Block assembly	-	Extra tripping brackets	+
	Grand block assembly	*Remain the same*		0
	Hull assembly	*Remain the same*		0
Outfitting	EMV-phase	Mode 1: Piping material processing and pipe installation *(out of scope)*	Module installation	-
	EMS/JMS-phases	Mode 2: Piping material processing and pipe installation	-	
	Area outfitting	-	Extra bleeding pipes	+
Commissioning	Onboard	Bleeding of AC-pipes at the borders of fire zones	Bleeding of AC-pipes at each maintenance triangle	+
Warranty	*Out of scope*			

The module usage has mainly increased the committed workload of different departments as can be noted from the table above. Its effects have been most significant for the departments of classification and hull basic design and the detail design of HVAC by increasing their committed workload remarkably. Although the study revealed that the design work of such departments has increased, it has to be noted that the increased amount of workload have been that significant only for the first vessel of the current ship series of six vessels. For the second and the following vessels there have been possibilities to take advantages by reusing the earlier done design work of the first vessel.

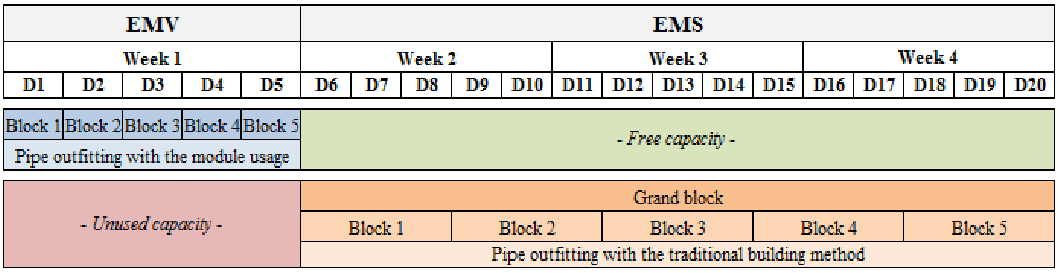
Reuse of a design work is one common characteristic and purpose of modularity with an urge to standardize product architectures and operations in order to achieve economies of scale (Campagnolo & Camuffo 2010; Hellström & Wikström 2005). In this study the earlier done design work for the ship hull and HVAC systems can almost be “copy-pasted” to the following projects because ships are sister vessels and mainly identical with each other especially with the hull structures and thus also with the pipe lines. Interior design has faced changes between the vessels, so there doesn’t likely to arise any extra design expenses due to the module usage after the first vessel. In reality, the last two vessels of the ship series are 20 meters longer than the first four vessels. Lengthening has also lengthened 10 meters the modules’ operating area. However, these changes and their effects were not taken into account in the study because they are not so remarkable. The study was performed based on the characteristics of the last two vessels while the other vessels were supposed to be similar with them.

The module usage created totally extra work stage and made changes to existing processes at the part fabrication phase of hull production due to the changes in the structures of T-bars. The most significant effects were formed because of bending of flanges and manual hand welding at the T-bars assembly phase. Moreover, lowered T-bars required extra tripping brackets in order to strengthen their structures. These manufacturing costs arise still from ship to ship and cannot be eliminated unlike design costs that were supposed not to exist after the first vessel. Naturally, modules’ prefabrication at the factory and logistics between the yard’s storages and the module factory are also extra work stages, although modules’ prefabrication is further straight away from the required pipe outfitting workload at the later process stages.

One of the most interesting targets of the study was from the very beginning module’s effects to the outfitting work. Although the module usage increased costs at the design work stages and at the part fabrication stage of T-bars’ manufacturing, the survey revealed that the module usage had huge effects for the lead time of pipe installation work at the block outfitting phases. Modules’ prefabrication decreased the workload at the EMV-phase remarkably because the work was almost entirely shifted to the factory where it can be done beforehand and also in parallel with other block fabrication processes. Thus, the remaining part of the pipe installation work in a block can be performed much more effectively due to the module usage.

The lead time of pipe installation work in the passenger cabin areas decreased to one third of the traditional building method due to the module usage. Installation of pipes with the traditional building method took an average triple a time required by the time used in the modules’ installation work. Furthermore, modules’ installation work is focused only at the EMV-phase while the traditional piping method delays and decentralizes the corresponding installation work at the later stages to the EMS- or even JMS-phases although it could be done already earlier at the EMV-phase as well.

Shifting the outfitting workload to further phases decreases the practical utilization rate of such outfitting facilities and lengthens the pipe outfitting lead time unnecessarily. The study revealed that the modules’ installation work to an explored grand block including five blocks took approximately five working days to perform while the traditional piping method required approximately three weeks to be completed. If one considers also the unused capacity at the EMV-phase in the case of traditional piping method, the lead time comparison between methods becomes even more substantial (see figure 30). Modules’ installation is labelled in blue and the traditional pipe outfitting in orange color in the figure.



EMV					EMS														
Week 1					Week 2					Week 3					Week 4				
D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20
Block 1	Block 2	Block 3	Block 4	Block 5	- Free capacity -														
Pipe outfitting with the module usage																			
- Unused capacity -					Grand block														
					Block 1			Block 2			Block 3			Block 4			Block 5		
					Pipe outfitting with the traditional building method														

Figure 30. Lead time comparison of pipe outfitting methods

Following tasks after modules and pipes' installation work were performed inside the vessel at the area outfitting phase after the hull assembly. As it was discussed and can be seen from the table 10, the module usage did not offer any advantages in terms of decreased costs after modules' installation work at the EMV-phase. Remaining distinctive tasks included duties such as coupling of AC cooling pipes from the corridor ceilings to the cabins' maintenance triangles and commissioning of pipe lines and systems. They were more favorable to do for traditionally built pipes because in the module's operating areas negative effects were formed due to the lower positioning of pipe lines at the corridor ceilings.

The following figure 31 (see also appendix 8) illustrates how additional costs due to the module usage are divided in relation to each other in a case of the first vessel of the ship series. The figure is based on the cost comparison between the usage of corridor piping module and the traditional piping method. It illustrates the cost difference as well as the relative shares between them. From the figure can be seen how the growing amount of design work covers approximately two thirds of the total extra costs. The rest one third of additional costs are formed due to material and module logistics, module fabrication, manufacturing of lowered T-bars as well as extra coupling and commissioning work of pipes. It should be noted that the figure illustrates only the distribution of additional costs in the case of the first vessel, while it does not take a stand with the reduced costs that arise from the block outfitting phases due to the improved and more effective pipe installation work.

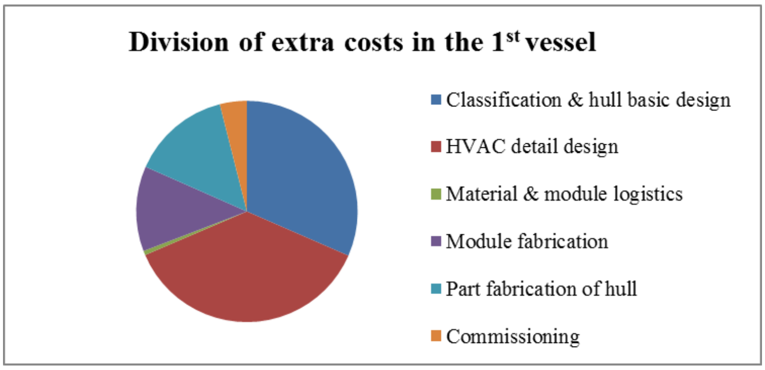


Figure 31. Division of extra costs

The following figure 32 illustrates the overall situation in terms of costs when the whole research scope is considered with all the process stages in the case of the first vessel. Green columns in the figure illustrate the cost difference between the module usage and the traditional piping method at each process stage, while blue columns illustrate the cumulative cost difference.

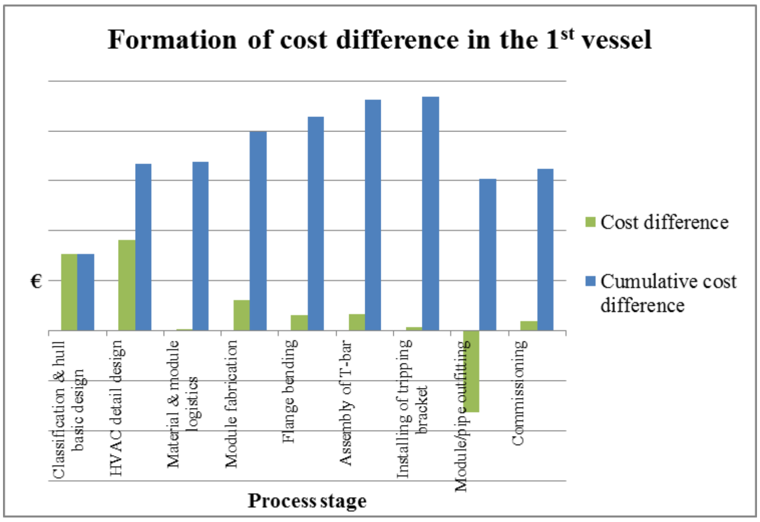


Figure 32. Cost formation in the first vessel

Possibility to reuse already done design work with the following sister vessels enabled to achieve remarkable cost savings in design costs that created the majority of additional expenses in the case of the first vessel. The formation of cost difference and corresponding cumulative costs in the case of the second vessel are illustrated in the figure 33. The same cost difference formation can also be applied for the third and later vessels after that because they are supposed to behave similarly.

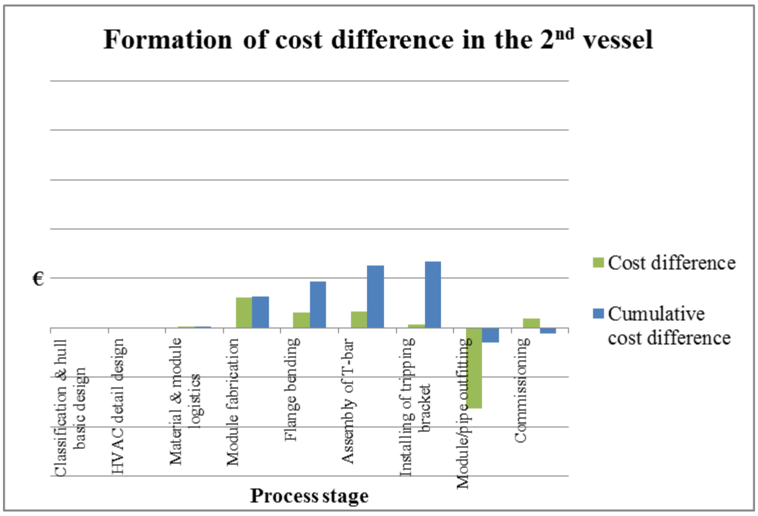


Figure 33. Cost formation in the following vessels

Other costs but design costs remain the same between the first and the following vessels because they are formed in manufacturing functions and cannot thus be eliminated. It can straight be seen from the figure 33 that the total cost effect of using the corridor piping module is much more favorable in the following vessels after the first one. Here the cumulative cost difference is slightly above the zero line at the end of observation period which signifies that the module usage became profitable after the first vessel where the cumulative cost difference was above the zero-line indicating additional expenses.

The following figure 34 illustrates differences in the behavior of cumulative costs in the case of the first and the second vessel. It describes well how the total cumulative cost difference reduces after the first vessel due to the heavily decreased design costs.

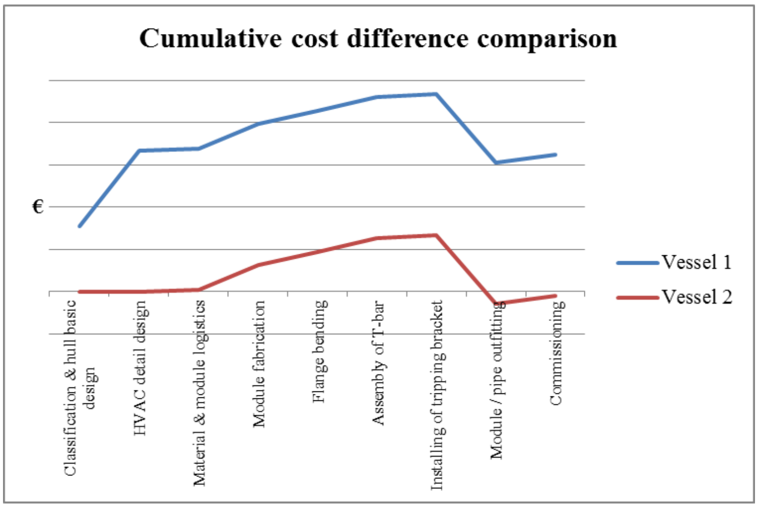


Figure 34. Cumulative cost difference comparison between vessels

The amount of costs savings which arose from the vessels after the first one is not very significant as can be noted from the previous figure. With the current course of actions and the product structure of the corridor piping module it does not pay itself back in the scope of these six sister vessels (see figure 35). This is mainly a result of the huge amount of additional design costs that arose from the first vessel. Vessels from two to six produce profit but the profit is not enough to decrease the total cumulative costs that arose from the previous projects in a way the module usage would become profitable in a scope of its usage in six vessels.

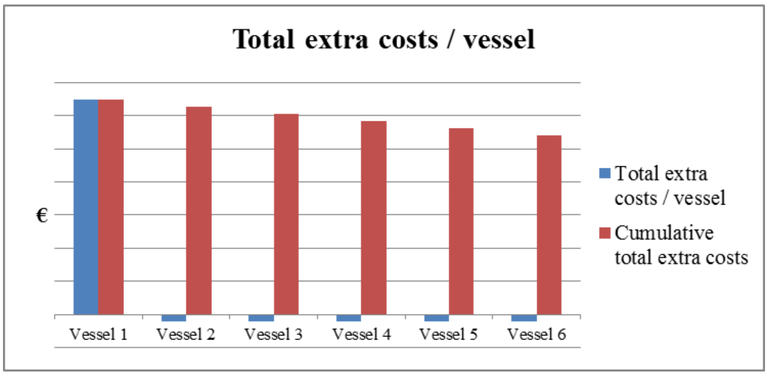


Figure 35. Cost behavior between projects

5.4 Fan coil unit module

Fan coil unit (FCU) module acts as the second modular case example of this thesis. FCU belongs also to HVAC category similarly to the corridor piping module. FCU is a device with the main feature to control either heat or cool the air temperature inside the vessel. The FCU under review of this study is a quite simple assembly that is placed at the crew gym of Mein Schiff vessels. Crew gym is located on the tween deck on the bottom of the vessel and it can be used only by the crew members of the vessel, so passengers are not able to access on such area. Generally, this type of cruise vessel may include up to couple of hundreds fan coil units placed at public spaces. Furthermore, each cabin has also its own fan coil unit so the total amount of fan coil units in a certain vessel rises vastly.

The aim of this study was to make a comparison and find out the cost effects between two different ways to construct and assemble the fan coil unit. The first one is called traditional building method that has been carried out over the past and one of the current projects. Traditionally, fan coil units have been constructed and assembled onboard at the area outfitting phase from the very beginning to the end of finalizing the area and commissioning of the device. Another way and the future aim is to minimize the outfitting workload onboard and shift the work to the factory and manufacture FCU modules in there. The FCU module can be manufactured at the factory up to a certain point of readiness and further transported to the vessel at appropriate time in relation to the progress of the shipbuilding project. Only the work which cannot or is not reasonable to be included into the module due to their nature, such as necessary installation work, work with interfaces or commission of the device as a part of vessel’s larger system will be done onboard.

This case study explores both construction processes in more details and pilots the modularization process with the main purpose to gather data during the processes from the cost effects point of view. The module utilizing manufacturing way has been executed for the first time at the yard during this Master's Thesis work. Thus, the nature of this case example and the starting point for the study is quite different compared to the first case example that has already been used for years within the past shipbuilding projects. At the moment, there are two identical Mein Schiff vessels under construction at Meyer Turku which have made it possible to perform the study in the chosen manner and gather data from the both shipbuilding projects. The fan coil unit of the first vessel is constructed with the traditional method and the latter one with the module utilizing method.

5.4.1 Module description

An overall structure of the fan coil unit is quite simple (see figure 36). On the left side of the figure can be seen what the FCU cabinet looks like as almost a ready at a crew gym and on the right side of the figure is its 3D model. As can be seen from the figure the fan coil unit is covered with interior walls and maintenance doors for service purposes.

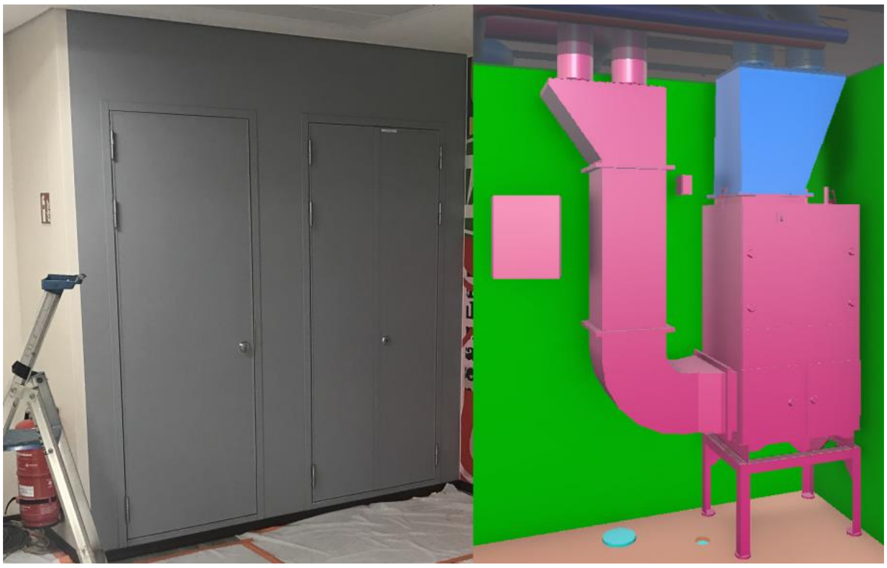


Figure 36. Layout of the current and past fan coil units

Fan coil unit's main components regarding on the modularization process are the FCU device itself, the electrical starter on the left side of the device, thin steel plate ducts for air inlet and outlet, pipes for water inlet and outlet as well as the foundation (stand) under the FCU device. The FCU device and its electrical starter are purchased from the external supplier while the air ducts and the stand are manufactured at the yard factories. Water pipes and other essential materials are stocked at the yard's storages and can be obtained from there.

During the modularization process, small changes were done for the layout and structures of the fan coil unit while the space reservation of the cabinet was kept exactly the same at the crew gym though (see figure 37). With the past and the first of the current projects there have been three maintenance doors in the FCU's cabinet but the new layout after modularization excluded the single door on the left side and enlarged the size of the double leaf doors in a way the accessibility for the components inside the cabinet became better.

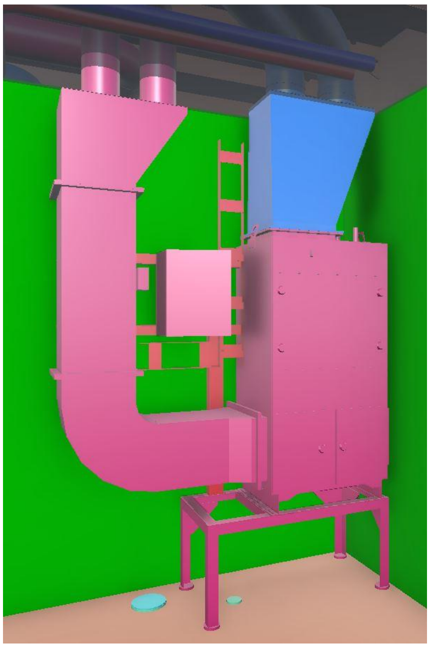


Figure 37. Layout of the fan coil unit module

Changes in the structures made it possible to move the electrical starter from the left between the air duct and the FCU device in order to improve FCU's serviceability and make the whole ensemble more compact by decreasing its footprint. This caused also changes to the structures and dimensions of the ducts and the stand. Air condition exhaust duct were lengthened on the left side of the FCU and the duct near the ceiling interface was turned around in a way its coupling point to the vessel stayed at the same position. The stand was lengthened up by prefabricating an upper frame to it in order to enable components' attachment to the stand at the module assembly phase. Modularization caused also a need to widen the stand in a way the module's balance remained stable.

5.4.2 Clarifying differences

In this case example, the research about the cost effects is also based on the comparison of committed workload between the traditional building method and building of the module at the factory. Case company's desire was to get detailed analysis about the efficiency in assembly operations between building methods, so the main emphasis was on these construction and assembly operations of the fan coil units. Inquiry based on the committed workload is a reasonable way to do the comparison because differences were supposed to arise just from the amount of required workload in assembly operations. Although there are small changes in the product structures of fan coil units, their elaborate examination in terms of consumed materials are excluded from the study and supposed to be the same because effects of these differences are so minimal.

Fan coil unit's traditional building method includes operations of components and materials procurement and storage, components prefabrication at the yard factories, components lift to the ship hull during the hull assembly phase, components and materials hauling to the crew gym after the hull assembly phase, materials processing onboard as well as the final construction and assembly of the FCU and the cabinet around the device. After the construction and assembly work are completed, the FCU will be commissioned as a part of the vessel's HVAC systems. Both building methods are explained with more details in the table 11.

Table 11. Building method comparison of fan coil units

Process stage	**Building method**	
	Traditional	**Module usage**
Design	-	Design of a module
Procurement	Procurement of materials and components	*Remain the same*
Storage	Storage of materials and components	*Remain the same*
Prefabrication	Prefabrication of a stand	*Remain the same*
	-	Prefabrication of the stand's upper frame and its installation to the stand
	Painting of the stand	*Remain the same*
	Prefabrication of air ducts	*Remain the same*
Module assembly	X	Installation of the FCU device, electrical starter and air ducts to the stand
		Electrical work and connection test
		Module protection
Hull assembly	Lift of the area's lower grand block to the ship hull	*Remain the same*
	Lift of the covered FCU device and the stand to the ship hull	Lift of the FCU module to the ship hull
	Lift of the area's upper grand block to the ship hull	*Remain the same*
Logistics	Materials and components logistics to the crew gym inside the vessel	*Less logistics needed due to the module usage*
Area outfitting	Hauling of the stand to its place	Hauling of the module to its place
	Installation of the stand to the ship hull	Installation of the module to the ship hull
	Installation of the FCU device to the stand	*Already done at the factory*
	Material processing and frame construction for the components installation	*Already done at the factory*
	Installation of the air ducts	*Already done at the factory*
	Installation of the electrical starter	*Already done at the factory*
	Electrical work and connection test	*Already done at the factory*
	Installation of the water pipes	*Remain the same*
	Work with interfaces	*Remain the same*
	Cabinet construction	*Remain the same*
	Interior work	*Remain the same*
Commissioning	Commissioning and adjustment of the FCU as a part of vessel's systems	*Remain the same*

Module usage enables to lift the complete prefabricated module assembly to the vessel and decreases required outfitting workload onboard. Otherwise, the module usage includes almost exactly similar operations as the traditional building method but all the construction and assembly that is reasonable to do and can be included to the module is performed in advance at the factory before lifting the module to the ship hull. From the previous table can be seen which operations are included to the module and another operations that are excluded from the module assembly. Excluded phases will be done onboard at the area outfitting phase so they remain similar in both building methods anyway.

The modularization project started initially from the design stage. The module usage required additional design work due to the changes in fan coil unit’s product structures, mainly in the structures of its air ducts and the stand. Existing detail design drawings and 3D models from the current project were updated to match made changes for the module. Furthermore, module’s assembly drawings were created for the factory purposes. Both fan coil units have exactly same components and their building processes require almost the same amount of materials as was discussed earlier, so more accurate exploration of these issues were excluded from the study. Thus, there are not any differences either in procurement or storage operations of components and materials. Main differences occurred in the following phases where the research core was also stood.

The overall frame of a module consists of the prefabricated stand and its prefabricated upper frame that is specially designed for the module usage. The upper frame of the stand enabled effective attachment of components in assembly operations. It includes also prefabricated cable trays for the electrical work purposes. The stand and the upper frame were manufactured at the yard factory, attached together and painted after that. At the module assembly phase, the FCU device was attached to the stand and the upper frame enabled the electrical starter and air ducts to be attached to it. In addition, cabling work between the electrical starter and the FCU device was performed at that time. Advanced done cabling work made it also possible to test the FCU and its functionality already at the factory. However, the final commissioning of the device should be done onboard because the FCU need to be installed as a part of the vessel’s HVAC systems in order to get it commissioned and adjusted completely.

When the module assembly was finished at the factory, the module was covered with protection material and lifted to the ship hull during the hull assembly phase. Crew gym is located between two overlapping grand blocks which made it possible to lift the module to the ship hull in between of the lift of these overlapping grand blocks. At that time in traditional building method, only the FCU device and its prefabricated stand are lifted to the ship hull. Traditionally, all the construction and assembly work related to the FCU are done onboard and they start much later. It takes couple of months before all other necessary hull and outfitting works are at the point in the crew gym that the work with FCU is able to start. This waiting period makes it necessary to protect FCU with a durable covering that prevents it to damage due to welding spatters and other tasks that happen in the area. Similarly, the FCU module was covered because the following tasks onboard can be continued also much later.

In the traditional building method, air ducts and the stand for the FCU device are prefabricated at the yard factories similarly to the module usage but the frame for the components' installation and the cable tray for cabling work is constructed onboard at the area outfitting phase simultaneously with the FCU's assembly and its components installation work. Frame construction onboard requires materials carrying into the vessel and materials processing before the frame can be constructed and components attached to it. Thus, there are differences in materials and components' logistics between the building methods. The module usage improved the efficiency in materials and components' logistics because it enabled them to be transported to the factory instead of the crew gym inside the vessel, being much more effective and easier to perform. In the module usage and the scope of this study, there was only one logistical operation from the pier to the vessel, the module lift itself. In the traditional building method, only the FCU device and the stand are lifted to the vessel at that time, while the electrical starter, air ducts and other required materials should be carried from the pier to the crew gym separately by hand or with the help of cranes.

Otherwise, construction and assembly operations of the fan coil unit in the traditional building method includes similar operations as the module assembly but the work at the factory is performed advance and can be done in industrial environment instead of inside the vessel. When the FCU's traditional building method has reached the same level of readiness as the module assembly, the following tasks remain exactly similar between building methods so there is no need to review them further. Those tasks include work such as installation of water pipes, work with interfaces between the FCU and the vessel, cabinet construction and other interior work related to the fan coil unit as well as the final commissioning of the FCU as part of the vessel's systems.

5.4.3 Results of the study

Accurate observations were performed during the building processes of fan coil units. In the traditional building method observations of construction and assembly operations were naturally performed inside the vessel at the area outfitting phase and in the case of the module usage observations were performed at the factory at the module assembly phase. Main differences were also observed at the design and prefabrication stages in order to get comprehensive results and the overall picture about the differences of building methods.

They survey revealed that the designer's extra work in designing of a module took one working day to perform all the necessary changes for the drawings and 3D models from the previous sister vessel as well as to produce module's assembly drawings. At the prefabrication stage, the difference in manufacturing of the module's widened stand with the upper frame took an extra hour compared to the manufacturing of the traditional stand. After these stages, the following findings were observed at the construction and assembly operations of the fan coil units. See table 12 to view a summary of the construction and assembly operations of the traditional fan coil unit and appendix 9 for further information.

Table 12. Task summary of the FCU’s traditional assembly method

1	Preparation at the crew gym	Unpacking the FCU device and the electrical starter
2	Installation of the FCU’s base to the stand	Detaching the base from the FCU and welding it to the stand
3	Installation of the FCU to the base	Lifting of the FCU to the base and attaching it to the stand by bolts
4	Installation of the upper right air duct	Attaching of the air duct to the FCU
5	Installation of the left side air duct	Attaching of the air duct to the FCU
6	Attaching of the left side air duct	Frame construction for the air duct, attaching and supporting the duct against the frame
7	Installation of the electrical starter	Frame construction for the electrical starter, attaching and supporting the starter against the frame
8	Electrical work	Construction of the cable tray, cabling between the FCU and the electrical starter
	Summary of assembly work [h]:	**9,7**

As can be seen from the table above, it took almost 10 hours to construct and assemble the fan coil unit onboard at the area outfitting phase. These assembly work hours are based only on the time consumed in construction and assembly operations onboard. Thus, they do not take a stand with neither materials nor components logistics to the crew gym or prefabrication of the components at the yard factories. Moreover, other works related to the FCU’s building process after finalizing its assembly such as cabin construction and interior work are excluded from these hours. The following table 13 summarizes corresponding time required by the module assembly method at yard the factory. See also appendix 9 for further information.

Table 13. Task summary of the FCU’s module assembly method

1	Preparation at the workstation	Unpacking the FCU device and the electrical starter
2	Holes drilling to the stand for the FCU installation	Lift of the FCU to the stand, holes marking, lift of the FCU off the stand, holes drilling
3	Installation of the left side air duct	Attaching of the air duct to the FCU
4	Installation of the FCU to the stand	Lift of the FCU to the stand, attaching it by bolts
5	Holes drilling to the frame for the electrical starter installation	Holes marking, holes drilling
6	Installation of the electrical starter	Attaching of the electrical starter to the frame by bolts
7	Installation of the upper part of the left side air duct	Coupling and attaching of the air ducts, attaching them to the frame
8	Installation of the upper right air duct	Attaching of the air duct to the FCU
9	Electrical work	Cabling between the FCU and the electrical starter
	Summary of assembly work [h]:	**4,2**

As can be noticed from the table above, there are small detailed differences in the construction and assembly operations between the traditional and the module assembly building methods, but the main steps remain the same. The survey revealed that it took only roughly four hours to complete the module assembly in the factory. Although there are small changes in the assembly operations, presented assembly work comparisons are equivalent for each other because both fan coil units are at the same point of readiness after assemblies are finished.

As a result of this assembly work research, the module construction and assembly were five and half hours faster to accomplish at the factory compared to the traditional construction and assembly method inside the vessel. At the same time, it means that the module assembly was exactly 57 % faster to accomplish compared to the traditional method. One significant reason to the efficiency in module assembly operations was the prefabricated frame for the components installation as well as its positive effects to the cabling work that quickened considerably. Changes in the module's product structures shifted the workload from the frame construction performed at the crew gym to the earlier phase of prefabrication of the stand at the yard's factory. In the traditional building method, frames for the components' installation are constructed onboard at the same time with component's installation work which delays the assembly lead time notably.

It should be noted that the above presented results concentrate only on the work in construction and assembly operations of the fan coil units. Thus, they do not tell the overall results of the building processes because design and prefabrication stages were excluded from those results. If one considers only the production operations of the fan coil units i.e. prefabrication and assembly operations, one extra hour should be added to the module usage that was consumed in manufacturing of the stand at the prefabrication stage. If this extra hour is added to the module assembly time, the overall result changes slightly. In that case the lead time of production operations was 46 % faster in the module usage compared to the traditional building method. Note that the presented result does not consider the total time consumed in prefabrication operations, but only the occurred difference that happened.

As it was discussed, the designer’s extra work took one working day in updating and creating of drawings and 3D models for the module. The whole building process comparison that considers in addition to production operations also the design stage is summarized in the figure 38 below (see also appendixes 10-11 for further information). The figure is based on the committed workload at each process stage and the values in the figure are measured in euros that are counted from the amount of such workloads. Blue columns in the figure illustrate committed costs in the traditional building method, while red columns illustrate committed costs in the case of the module usage. Green columns figure out the cumulative costs difference between the building methods.

At the design stage, the figure illustrates the amount of additional costs that arose from the module design. Thus, the amount of design work in the traditional method is supposed not exist and only the distinctive part is considered. At the prefabrication stage, the figure considers costs that arose in manufacturing of the stands and makes comparison from that point of view. Costs that arose in manufacturing of air ducts are excluded from the figure because they were supposed to be the same. Last columns at the assembly phase consider all those costs related to the construction and assembly operations that were identified during the study in set limits.

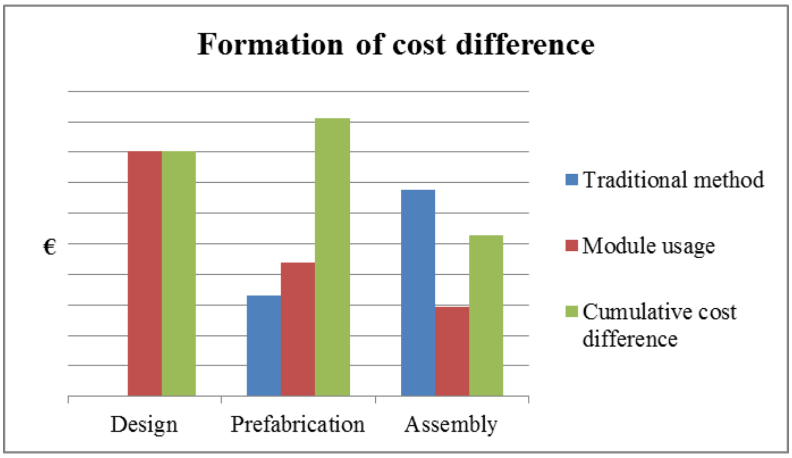


Figure 38. Cost difference comparison between building methods

As can be seen from the figure, the majority of costs form already at the design stage in the module usage. In the case of the traditional building method, design costs are counted nothing because the design for the FCU was already done for the previous vessel and can be taken as ready from there. Thus, the distinguish factors were only taken into account. Although the design changes of the module were quite negligible, their effects are much more significant for the final results of the whole modularization project.

At the prefabrication stage module usage becomes a bit more expensive compared to the traditional method due to the changes in the stand’s product structures and thus, in longer manufacturing period of it. At the assembly phase the module usage produces profit due to the more effective and shorter assembly operations compared to the traditional building method. This profit is however not enough to cover those extra costs that arise from the design and prefabrication stages, which makes the module usage unprofitable in this project where the module is used at the first time. As the figure illustrates, the cumulative cost difference is clearly above the zero at the end of observation period.

6 DISCUSSION

Two distinct module case examples were explored in this thesis. The aim of the research was to clarify the cost effects of modularity utilization. Current literature provides great amount of positive effects of modularity (see e.g. Pahl et al. 2007, p. 508-509). Many of those benefits consider also costs and argue that modularity brings advantages in terms of costs. However, there are challenges to utilize modularity in a complex project business environment such as in a case company context of shipbuilding industry. Challenges occur mainly due to the complex product structures and the lack of constant repetition between product deliveries (Hellström 2014). Ship deliveries are typically very different from a certain project to another although the current ship series of Mein Schiff vessels has been historic long for the case company because only one totally different vessel is built in between of this series.

Selected module case examples explored in this thesis were deliberately quite different entities making the researches different and providing results from two different points of view. The first case study was more extensive compared to the latter one because the corridor piping module has affected to several departments and their operations while the effects of the fan coil unit module have touched fewer departments. Obtained results of case studies will improve yard’s understanding about the cost effects of modularity utilization as well as offer significant information for their further purposes in exploring and developing of operations in a modular shipbuilding context.

At the moment it is a common feature to build areas and systems during several outfitting phases in which case such workload is also divided into many parts and several phases. In some cases, it is understandable phenomenon because of the nature of such systems and their building methods. However, modularity strives to accelerate building processes and gather the current workload from site to module assemblies which can be manufactured at the factory in advance with more effective and better working conditions. In that case complete module assemblies will be transported from the factory to the vessel at the most appropriate time and favorable phase of outfitting in relation to the progress of the shipbuilding project and installed after that. The figure 39 below illustrates this general aim of modularization in the yard environment.

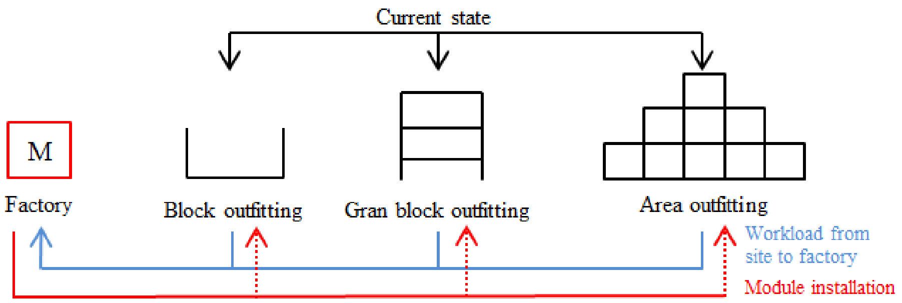


Figure 39. Outfitting workload distribution

6.1 Corridor piping module

The first case example focused on the corridor piping module that is used in the ship series of Mein Schiff vessels constructed at the Meyer Turku. The research about the cost effects of module usage covered almost all shipbuilding process stages and departments that are related to the piping of passenger cabins in the set limits. Consequently, only the sales phase and warranty issues after vessel delivery were excluded from the research study. In the study the corridor piping module was compared to the non-module utilizing building method to outfit exactly same pipes in other passenger cabin areas inside the same vessel. The study revealed that the module usage has had huge effects - both positive and negative effects in terms of costs during the shipbuilding project execution.

Module usage created remarkable differences to the traditional pipe outfitting work. Positive effects of the module usage form at the EMV-phase of block outfitting when the corridor piping modules are installed to blocks of a ship hull. Its major advantage is to make the pipe installation work at the EMV-phase much more effective compared to the traditional piping method. The module usage decreases significantly the lead time of such pipe installation work. Effectiveness at the yard side is enabled by prefabricating modules in advance at the module fabrication factory outside the yard. Prefabricated modules are installed early to blocks at the time blocks are still upside down and when the installation is preferable to do due to the possibility to do down hand work. Installation work of prefabricated modules at the EMV-phase includes only jointing of modules' interfaces together and attaching them to the lowered T-bars of blocks.

In traditionally built areas, the pipe outfitting work starts only later at the following EMS-phase of grand block outfitting when the blocks have already turned around and assembled to grand blocks. In such areas there is not any prefabrication of pipes unlike in the areas of module usage. Consequently, the traditional pipe outfitting work starts with the raw material carrying to the grand block and its processing in there. Thus, all the raw material processing that is done beforehand for the module at the factory is done at the EMS-phase in that case. After the raw material processing pipes are installed to the corridor ceilings. Such installation work should be done up hand being more inefficient and challenging to do compared to the down hand installation work of modules.

Although the traditional pipe outfitting work could also be done earlier at the EMV-phase similarly to the modules installation, the responsible pipe outfitting contractor transfers the starting point of such pipe outfitting work at the later outfitting phases. Work transferring to the following phases cause unnecessary under capacity to the EMV-phase by decreasing production efficiency and the practical utilization rate of such outfitting facilities meanwhile it also increases the total lead time of such pipe outfitting work. Sometimes there have also been challenges to complete the pipe outfitting work at the EMS-phase due to the tight schedule in which cases it should be continued later, after the grand block painting at the JMS-phase. After the traditional pipe installation work has been completed at the EMS- or JMS-phase, both reference areas are at the same level of readiness.

However, in the blocks of modules' operating areas such readiness has already been achieved much earlier.

As the study revealed there are also lots of disadvantages due to the module usage. Negative effects in terms of additional costs were mainly formed because the corridor piping module was designed only after the hull structures of the first vessel were already designed. As a result of this department of classification and hull basic design was forced to redesign all the hull structures at the modules' operating areas. Redesign of hull structures caused huge amount of extra work and costs due to the incoherent order of design work. Moreover, redesign of T-bars reflected to their manufacturing process by causing additional process stage and delaying their manufacturing lead time. Module usage increased also remarkably the workload of HVAC detail design department because they were supposed to produce detailed manufacturing drawings for each module in order that the module fabrication factory is able to manufacture them.

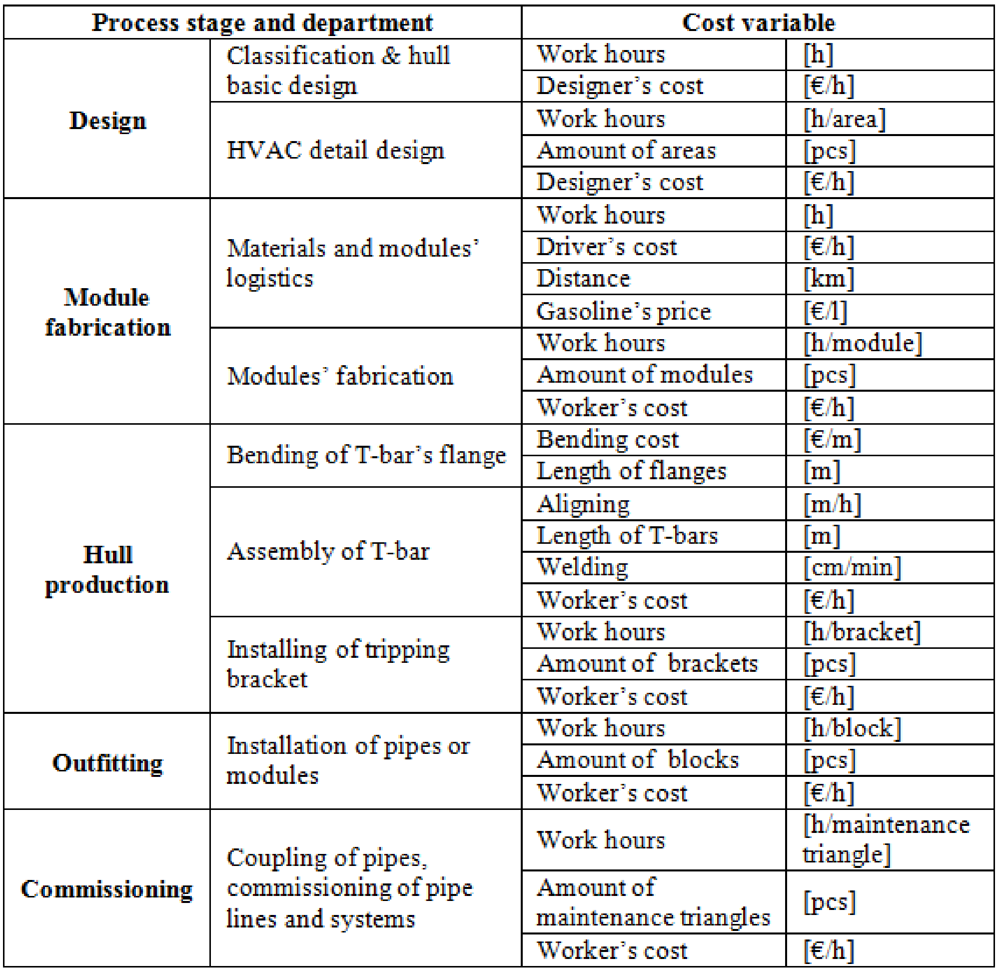
Following significant differences between building methods occurred at the area outfitting phase after modules and pipes have been installed to blocks and the pipes' coupling work from the corridor ceilings to the cabins' maintenance triangles is getting started. In the modules' operating areas coupling of AC cooling pipes is more difficult to do due to the positioning of air conditioning cooling pipe lines at the corridor ceilings. Consequently, each maintenance triangle requires installation of an extra bleeding pipe for the AC cooling pipes. Furthermore, each maintenance triangle needs to be bled separately causing extra work for commissioning of such pipe lines and AC systems. Traditionally, air conditioning cooling pipe lines are bled only at the border of each fire zone.

After summarizing together all those positive and negative effects that were identified to arise due to the module usage during the research study, the results revealed that the usage of the corridor piping module became unprofitable in terms of costs. The module usage became more expensive for the yard compared to the traditional piping method in the case of the first vessel of the ship series. Expensiveness and unprofitability were mainly a result of two characteristics: the significant changes in the structures of T-bars and the detail design work of HVAC department. Requirement to lower traditional T-bars included a great amount of additional design work for the classification and hull basic design department. Furthermore, modules’ detailed manufacturing drawings and their accurate modelling caused significant amount of extra work for the department of HVAC detail design. These features together caused a huge amount of extra costs which cannot be paid back by the advantages that arose from the module usage at the later stages of project execution.

As it was discussed, the ship series of Mein Schiff vessels includes total six sister vessels where the corridor piping module has been used. The module usage proved to be much more favorable in the following vessels after the first one because there was an ability to reuse the already done design work of the first vessel. As stated, the design costs created majority of the additional costs in the case of the first vessel. In the following vessels the costs of design work were eliminated when the cost calculations changed considerably. Naturally, manufacturing work still exists with the following projects including T-bars manufacturing, logistics and module fabrication, module installation as well as pipe coupling and commissioning operations. Decreased design costs made the module usage profitable in the following projects after the first vessel. However, the cost savings that arose from the following single vessels are really small compared to the additional costs that arose from the first vessel. As a result of additional costs of the first vessel, they cannot be totally paid back by the cost savings that arose from the following projects after the first one.

One obvious fact that should be considered is the price of a design work that is significantly higher for the yard than the price of the manufacturing work which reflects also to the final results of this study. Other tasks during the study are mainly production related activities which are cheaper to perform. Cost variables that have been identified and used in cost calculations over the research are listed in the table 14 below. They are categorized chronologically according to project execution and different departments.

Table 14. Cost variables of the first case study



Process stage and department		Cost variable	
Design	Classification & hull basic design	Work hours	[h]
		Designer's cost	[€/h]
	HVAC detail design	Work hours	[h/area]
		Amount of areas	[pcs]
		Designer's cost	[€/h]
Module fabrication	Materials and modules' logistics	Work hours	[h]
		Driver's cost	[€/h]
		Distance	[km]
		Gasoline's price	[€/l]
	Modules' fabrication	Work hours	[h/module]
		Amount of modules	[pcs]
		Worker's cost	[€/h]
Hull production	Bending of T-bar's flange	Bending cost	[€/m]
		Length of flanges	[m]
	Assembly of T-bar	Aligning	[m/h]
		Length of T-bars	[m]
		Welding	[cm/min]
		Worker's cost	[€/h]
	Installing of tripping bracket	Work hours	[h/bracket]
		Amount of brackets	[pcs]
		Worker's cost	[€/h]
Outfitting	Installation of pipes or modules	Work hours	[h/block]
		Amount of blocks	[pcs]
		Worker's cost	[€/h]
Commissioning	Coupling of pipes, commissioning of pipe lines and systems	Work hours	[h/maintenance triangle]
		Amount of maintenance triangles	[pcs]
		Worker's cost	[€/h]

As it was discussed earlier and as the table above shows, the research about the cost effects of modularity utilization was performed by concentrating mainly on the required workload at different stages of the project execution. Both building processes were explored in details and major differences between them were identified by using the cost variables presented in the previous table. Consequently, committed work hours to complete certain tasks are the major variables that determine the total cost effects of modularity utilization in this case example. Moreover, some other variables were also identified such as in the flange bending the used cost variable was euros per bended flange meter [€/m] while the welding costs were calculated based on the amount of welded centimeters per minute [cm/min]. See the previous table to view more examples.

Modularity utilization created additional costs that do not occur in the areas that are built traditionally i.e. non-modularly. As a summary, module usage caused extra design work for the departments of classification and hull basic design and HVAC detail design. Furthermore, module's prefabrication outside the yard created costs that differ also from the non-modular way of work. Those costs include logistics costs of materials and modules as well as modules' manufacturing costs. Following cost difference happened at the part fabrication stage of hull production where the flange bending in manufacturing of lowered T-bars created totally new process stage. Moreover, T-bars assembly caused extra costs because it was delayed due to challenges in aligning of parts together, due to the requirement for hand welding instead of being able to use automatic welding machine as traditionally and due to the requirement to install extra tripping brackets to T-bars created. Last additional costs due to the module usage occurred in coupling of AC cooling pipes from the corridor ceilings to cabins' maintenance triangles and in commissioning of such pipe lines and systems.

In an idealistic situation the module will be designed and used in a way all the extra costs will be minimized as small as possible, whereupon the profit due to the module usage increases. In such an ideal case the module usage would become profitable as soon as possible, perhaps already in a case of the first vessel. With the current module product structure and use cases, additional logistics costs are easily eliminated by manufacturing modules at the yard because all the materials are stocked at the yards' storages. Moreover, modules' manufacturing does not need any special equipment and facilities, so they can be manufactured under quite simple conditions in small space requirements. Manufacturing of modules at the yard would improve also timing of their production to respond better to the actual need and decreases the need and time spent for their storage. However, logistics costs divide really small share of the overall total costs so more significant changes should be made in order to improve module’s cost effects.

In the most idealistic situation the department of classification and hull basic design does not need to perform that much work in redesigning of hull structures. Either the needed design work of hull structures should be known a lot in advance in a way designer do not need to do changes for the hull structures afterwards or the current hull structures should be considered in designing of the module in a way they can be utilized as such. The latter option means that the module should be designed and used in a way it could be installed through the lighting holes of T-bars, similarly to pipes in the traditionally built areas. Moreover, repositioning of modules would also eliminate the need to install extra bleeding pipes for AC cooling pipes to each maintenance triangle. At the same time, it would eliminate the need to bleed each maintenance triangle separately. Moreover, the current amount of different module variants and drawings should be decreased in order to intensify design and manufacturing as well as outfitting operations.

All those above listed features are the most explicit changes that should be considered in the future in the following shipbuilding projects in order to improve and get the usage of the corridor piping module more idealistic and profitable. Features should be considered at early design phases in order the extra work and negative effects are minimized or totally eliminated. In the figure 40 below is an illustration of the cost formation in an idealistic situation. As can be noted all the extra costs are eliminated and the cumulative costs difference is clearly under the zero line at the end of the observation period which means that the module usage is highly profitable from the very beginning. This example is based on the same values gathered during the research study but all the extra costs due to design, logistics, T-bars’ manufacturing and commissioning are eliminated from the illustration. Module fabrication and their installation costs remain the same.

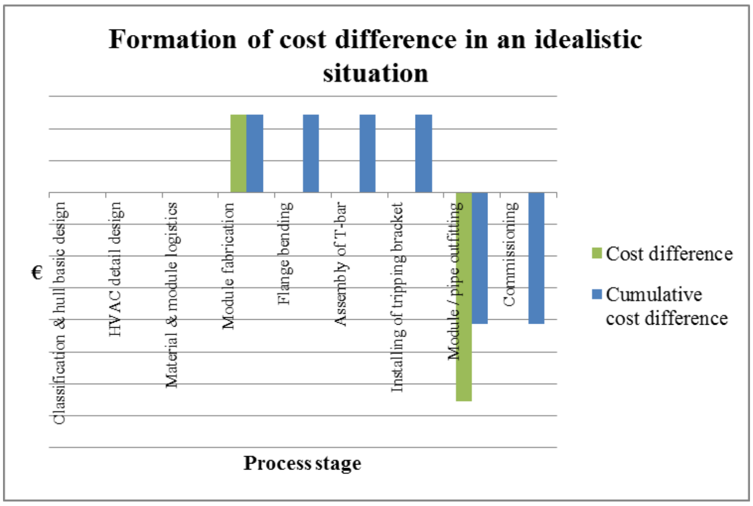


Figure 40. Cost formation in an idealistic situation

Presented cost formation of the idealistic situation might be unrealistic and really challenging to achieve in reality. For example, design costs are totally eliminated from the figure and supposed not to exist at all. However, the figure and mentioned development targets set guidelines for the future direction that should be tried to reach in the following shipbuilding projects in order to develop the current state of the module usage. In the most idealistic situation, the product structure of a module is designed once and standardized in a way it can be used as such over several projects without a need to do any changes for it. It requires careful design and perhaps couple of different product variations but decreases the complexity significantly and offers many advantages.

6.2 Fan coil unit module

Fan coil unit module was developed and used for the first time at the yard during this Master’s Thesis work. It was a result of the modularization project whose aim was to develop the module systematically by using the principles of concurrent engineering (see e.g. Graf 2016, Stjepandić et al. 2015, Whitney 2004). Traditionally with the past projects fan coil units are constructed and assembled inside the vessel at the area outfitting phase but the module was built at the yard’s factory outside the vessel. The main objective of this study was to compare building methods and gather data during the construction and assembly operations of the fan coil units from the cost effects point of view. As it was noted during the research process, there are lots of similar operations where do not exist any differences between the building methods and operations that are different with each other. Differences in the building methods made the results of this study.

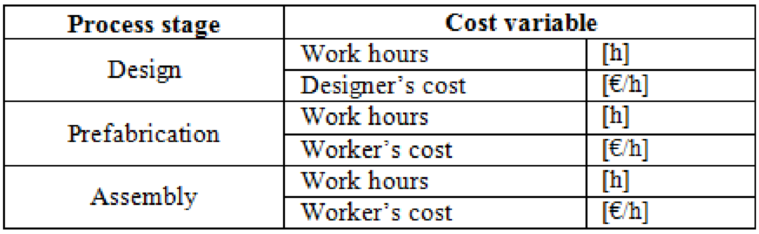
The first remarkable difference in a module usage occurred already at the design phase when the module assembly needs to be designed. The module design was based on the drawings and models of the fan coil unit that have already been done for the previous vessel. Module's additional design work consisted of updating of those existing drawings and 3D models from the previous project in order they are equivalent to the changes that were done for the fan coil unit's product structures during its modularization project. Furthermore, module's assembly drawings for manufacturing purposes were also produced at that time. In the research study, the design work required by the traditionally built fan coil unit was supposed not to exist and the difference in design works between building methods was the amount that occurred in designing of the fan coil unit module.

At the prefabrication stage, differences between building methods were formed due to the changes in the product structures of the module's stand. Although there were also changes in the structures of air ducts, their effects were not considered because made changes did not have effects to the committed workload in their manufacturing processes. Changes in the product structures of the module's stand delayed its manufacturing process when compared it to the manufacturing of the traditional stand because the module's stand included also frames for the components installation.

Following differences were formed at the assembly phase where was also the main point of case company's interest regarding of this case study. The survey revealed that the construction and assembly of the fan coil unit module was much more effective to perform at the yard's factory compared to the FCU's traditional building method done onboard at the crew gym area at the area outfitting phase. Assembly work comparison proved that the module assembly decreased the lead time of assembly work up to 57 %. If one considers also the prefabrication stage together with the durations of assembly phases, the amount of lead time savings was 46 % in the module usage.

Cost variables that were identified during the research study and were used in the cost calculations are listed in the table 15 below. See appendix 10 to view further information of the calculations. Exactly same cost variables exist in both building methods so there are not any differences between them. Differences and variations were identified only in the amount of committed workload of such operations.

Table 15. Cost variables of the second case study



Process stage	Cost variable	
Design	Work hours	[h]
	Designer's cost	[€/h]
Prefabrication	Work hours	[h]
	Worker's cost	[€/h]
Assembly	Work hours	[h]
	Worker's cost	[€/h]

As an overall result of this case study, the usage of the fan coil unit module proved to be unprofitable for the case company when all the process stages i.e. design, prefabrication and assembly are considered together. Expensiveness was formed due to the amount of module's additional design work and its high price, similarly to as it was in a case of the corridor piping module. The increased amount of prefabrication in the module usage was also a single additional cost when comparing it to the amount of prefabrication in the traditional method. However, the increased prefabrication was a precondition for the effectiveness at the later assembly phase so the increased work at the prefabrication stage was favorable in this sense. Cost savings that arose at the module assembly phase due to the much more effective operations were not enough to cover those additional costs from the previous stages in which case the module usage proved to be more expensive for the yard compared to the traditional building method.

The following figure 41 (see also appendix 11) illustrates an imaginary future idealistic occasion where the same FCU module is used for the second time in the following sister vessel. As can be seen from the figure, in this imaginary idealistic example design costs are eliminated because the design work can be taken as such from the previous i.e. from this project. Prefabrication and assembly operations remain the same when the cumulative cost difference states that the module usage becomes profitable already right in the second project the module is used in.

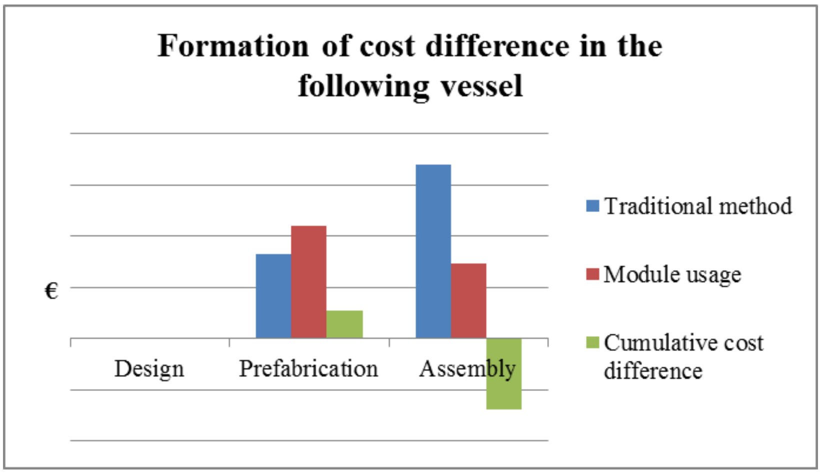


Figure 41. Cost formation of the module usage in the following vessel

Above presented figure is based on the same values that were gathered during the research study. In reality, it is obvious that there is an opportunity to intensify also prefabrication and assembly operations further. It could be possible to achieve especially in a project where the amount of fan coil unit modules is higher in a way there is repetition in prefabrication and assembly operations. Thus, there is naturally also an opportunity to gain increased amount of profit due to the possibility to achieve scale of economies in manufacturing operations because of kind of features of mass production. By expanding the usage scope of fan coil unit modules, the repetition and profit would increase more and more. This could be achieved by standardizing the module's product structure in a way it could be used as such in different places in the vessel and also within several shipbuilding projects while the total amount of different module variations should be kept low.

7 CONCLUSIONS

This Master’s Thesis offered a research about the cost effects of modularity utilization in a complex operating environment of shipbuilding industry. From the current literature one can find very limited amount of researches that consider the cost effects of modularity utilization (Campagnolo & Camuffo 2010). SPAR (2011) and Andritsos & Perez-Prat (2000) offer estimates that support the thought in shipbuilding environment arguing that outfitting work is favorable, more effective and thus also cheaper to perform at as early phases of the shipbuilding project as possible. However, there exists a lack of explicit examples and studies in a case company context that prove those facts. These foreknowledges inspired to do this study and investigate the topic in more details by exploring two concrete module case examples.

The research started with a literature review on topics of project business, modularity and modularization as well as cost management. Case company’s processes were also introduced in more details in order to create appropriate frameworks and understanding about the case company context and the research scope. The latter part of the thesis concentrated on the practical research about the cost effects of modularity utilization by exploring the topic through two distinct module case examples. Examples were selected in a way they support case company’s current projects and their urge in the best possible way. Activity-based costing method was utilized in cost calculations with a bit simplified form by exploring only direct (variable) costs while indirect (fixed) costs were excluded from the studies. Other limitations made were introduced during the case studies.

Both case studies verified strongly the argument and assumption that modularity utilization speeds up the assembly operations of outfitting work in the shipbuilding environment. Explored case examples revealed that the usage of prefabricated modules has huge effects for the effectiveness of outfitting work done at the block outfitting phases. Modules usage reduced the lead time of such outfitting work remarkably compared to the traditional building methods. Recognized advantages in terms of costs savings were mainly identified just in the reduced time of construction and assembly operations. Explored module assemblies were manufactured at the factories with industrial environment when their construction and assembly were more effective to perform due to the better and more effective working conditions. Shifting the workload from the yard site to the factories made it possible to perform tasks in advance as well as in parallel with other tasks at the yard site. Parallel manufacturing minimized the workload on site in a way the obtained results were able to achieve.

In addition to these advantages achieved, there occurred however also several disadvantages in terms of increased expenses due to the module usage. The most significant additional major cost in both examples was formed due to the increased amount of design work that influenced also strongly to the overall results of case studies. Based on the findings made, it seems that the usage of a certain module becomes more expensive compared to the traditional non-module utilizing building method when it is used for the first time and all the process stages from the design phase to the end of finalizing the assembly are taken into account. It happens only just because of the great amount of design work needed and its high price compared to the price of manufacturing work in general. However, explored case examples stated that cost savings will arise from the following projects after the first one if the module can be used as such in a way there is no need to perform any design work again related to the module usage.

Although the overall results of both case studies argue that there are additional expenses due to the module usage, their effects to accelerate outfitting operations are really remarkable and valuable. From the manufacturing and outfitting work point of view, design functions can be thought to be supportive functions that enable to intensify outfitting work. Furthermore, more time spent to the design work, might also make it possible to decrease the total lead time of the shipbuilding project in the future. Explored case examples cover small share of the huge totality of the outfitting work tasks but they offered guidelines that support thoughts about positive effects of modularity utilizing in order to accelerate the outfitting work at the yard. It is a worth of further exploration to contemplate how much is the reasonable amount and how much the yard is willing to pay for increased design costs if they will enable to decrease the total lead time of the shipbuilding project. It is obvious fact that the yard should find ways to quicken the construction lead time of shipbuilding projects in the future in way they are able to respond for the market competitiveness as well as reach the goals they have set for themselves.

Furthermore, current module assemblies should be developed in a way more idealistic module use cases can be achieved, and new alternatives should also be found in order to develop the current state of shipbuilding. Exploration of the first case example raised thoughts about missing concurrent engineering way of working when the module was developed among those departments that are closely related to the module usage. The huge amount of negative effects and the lack of consciousness about module’s existence at the yard support these thoughts. From the author’s point of view there are lots of possibilities and potential to develop the module in the future. With better design and communication work the final solution of a module could have been better with fewer disadvantages in terms of its usability and cost effects.

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APPENDIXES

Access to appendixes of the thesis is limited due to their sensitive and confidential material. For further exploration, contact either the author or Meyer Turku for request more information about them.