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Modular Capabilities on Offshore Support Vessels

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Background

The international offshore support vessel sector has had a distinct growth the past recent years. And it seems that this growth will only continue in the near future. The demand for offshore support vessels continues to grow as a result of more deep water projects, subsea work, longer distances between installations and higher safety regulations.

The maritime sector faces a challenge in increasing the operating areas for each vessel. The flexibility of each vessel today is rather limited and an increased knowledge on this matter will be of significance both for the environment and reducing the cost for the vessels. Ship brokers can reduce their fleet, having fewer and more flexible vessels.

Overall aim and focus:

The overall aim of the thesis is to validate and develop opportunities to increase the range of possible operations for offshore support vessels by reconfiguring installed modules on the vessels.

Scope and main activities

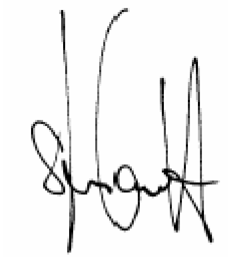
The candidate should presumably cover the following main points:

- Give a short overview on the background of the project i.e. modularity, modularity in design, product design etc.
- Provide a summary of existing technology on the market today.
- Explore and identify advantages and disadvantages related to increased operational flexibility on offshore support vessels.
- Based on previous findings undertake a concept evaluation of the introduction of modularity to increase operational flexibility on offshore support vessels.
- Undertake a concept comparison between vessel from the modern fleet of offshore support vessels and a vessel with modular capabilities considering the factors found in the previous tasks.
- Develop a methodology to identify modules, their interactions with the vessel and other modules and create an equipment structure for the vessel.

- Create an outline specification and perform a case study where the methodology is used to structure the modular capabilities and the belonging equipment modules.

Modus operandi

The responsible advisor will be Professor Stein Ove Erikstad at NTNU.



Stein Ove Erikstad

Professor/Responsible Advisor

PREFACE

This master thesis was written as part of my Master of Science degree in Marine Technology with specialization within Marine Systems Design at Norwegian University of Science and Technology in Trondheim. The thesis is written in the spring of 2012 and the workload corresponds to 30 ECTS. The problem description has been developed in collaboration between my supervisor professor Stein Ove Erikstad and myself.

The thesis is a two-way split between a concept evaluation of modular capabilities on offshore support vessels and to develop a methodology to establish the equipment structure and exchange intervals for the vessels.

I would like to thank my supervisor, professor Erikstad, for providing me with both valuable literature on the subject and also guidance toward the result of this master thesis.

Writing this master thesis has been a valuable experience for me, I have learned many valuable things and among these are; that dead ends can be avoided by adjusting your approach and that behind innovation there lies many hours of thoughts, both good and bad. I have also learned to write down good ideas as they come because they tend to vanish equally fast as they come. Last, but not least I have increased my knowledge within product development and also within offshore support vessel design and operation.

Trondheim, June 8th 2012

Øystein Brekke

EXECUTIVE SUMMARY

The report is divided into three different categories; background, concept evaluation and comparison and the methodology development. The background gives a short introduction of product architecture, modularity and modularization and also a brief description of existing design concepts which are capable of offering modular capabilities in the operation phase of a vessels life cycle.

The second part of the report is a review of possible advantages and disadvantages with the implementation of a similar concept as presented in the background on offshore support vessels. The review deals with several aspects such as increased flexibility, higher spot utilization and also how this concept can have effects in an environmental perspective. Direct challenges with modular capabilities such as equipment complexity, port logistics issues etc. has also been discussed. Finally the concept is evaluated from an economical perspective, discussing costs in short and long term perspectives and how to predict the costs of a conversion between operations.

The result of the evaluation is that the concept has aspects that are presumed quite beneficial for ship owners. Noticeable are increased flexibility in the range of operations a vessel can perform, possibilities for a fleet reduction due to modular capabilities and also possibilities for economic benefits in forms of higher spot utilization and easier maintenance of equipment modules. It is also anticipated that the concept will make the vessel more receptive for new technology and equipment modules. The most repressive aspect regarding modular capabilities is by far each equipment modules high degree of complexity together with the low degree of independency.

The concept has also been compared with multi-purpose OSV's and conventional mission specific OSV's within several different aspects considered important for ship owners. The results are generally favoring a vessel with modular capabilities, but also that the negative aspects of the concept might not be taken sufficient account for in the comparison.

In the third and last part it is developed a methodology to establish the equipment structure of an offshore support vessel with modular capabilities. It establishes the function hierarchy of the vessel and defines the interactions between the equipment modules and the functions before each module is evaluated in light of modular complexity and vessel influence. Based on this the equipment structure is established and exchange intervals for the modules are proposed.

To illustrate the steps of the methodology better a case study is performed based on 5 different operations; anchor handling, towing, pipe lay, construction and support. The case study gives two main indications:

1. There are a potential in further development of the methodology. Mainly involving the modules interactions and the specific equipment evaluation.

2. The equipment modules are as determined before very complex and require long exchange intervals and also extensive external support to swap modules.

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ABBREVIATIONS

AHTS	Anchor Handling, Towing and Supply Vessel
CSV	Construction Support Vessel
ECA	Emission Control Area
DSM	Design Structure Matrix
IMO	International Maritime Organization
MCM	Mine Countermeasure
MDS	Modular Design Strategy
OSV	Offshore Support Vessel
PSV	Platform Supply Vessel
ROV	Remotely Operated Vehicle
RDN	Royal Danish Navy
TRL	Technology Readiness Level

1 Introduction

Exploration and oil production activities are advancing into deeper waters and drilling operations are conducted in harsher conditions which is creating a certain shift in the design of OSV's. There are higher requirements for the vessels mission performance, endurance and as always a pressure to reduce costs. Over the pasts years there has been a development of concepts on military vessels allowing the vessels to offer higher operation flexibility. Utilizing modular approach the vessels are able to conduct far more operations and at a lower cost.

Is it possible to transverse the same modular approach used on military vessels to offshore support vessels in order to offer a higher range of operational flexibility to meet the rapid development in the market? To answer this question I will draw parallels between military vessels and offshore support vessels in light of the concept modular capabilities and by this recognizing possible advantages and disadvantages.

In the case where modular capabilities are proven beneficial for offshore support vessels, how can the equipment for the modular capabilities be structured and how can an exchange interval for the modules be determined? By using basic product design and development theories I will develop a methodology that is capable of structuring the equipment and indicate exchange intervals.

PART I - BACKGROUND

Part I gives a review of the theoretical background used as foundation for the further work in this report. It is a three way split between product architecture, modularity and state of the art technology survey. The emphasis in this report has been placed on the two latter.

2 PRODUCT ARCHITECTURE (HÖLTTÄ-OTTO, 2005)

Product architecture has many different definitions, but are in all ways a representation of a given system or product. The representation of product architecture is either in a physical way e.g. the physical components of a product or an abstract approach where functions of the product are described and mapped. Functions are operations that a set of components carry through e.g. for a printer machine a function is retrieving paper or distributing ink to the paper. Product architecture can also represent the relations between the physical components and the abstract functions. This is done to systemize the modules and their respective functions together e.g. for the printer one abstract function was retrieving paper and this specific function requires the components storage room for paper and rollers to transport the paper.

Another positive feature of the product architecture is the visual representation of the product. It becomes easier to understand the design and its interactions as well as being helpful to develop the design further.

The simplest way and probably the most common to represent the product architecture is by a hierarchal tree structure. Figure 2-1 shows how a system and its sub systems normally can be represented in a tree structure.

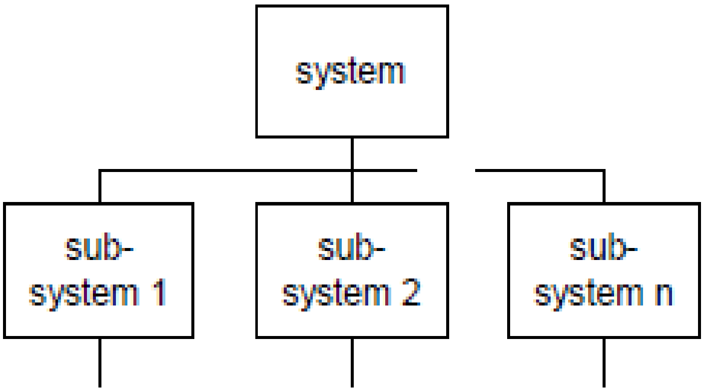

Figure 2-1 A hierarchal tree structure for a system and its sub-system

3 MODULARITY

Modularity has been well known for over several decades. The concept of a hierarchical system that further consists of independent sub-systems was introduced already in early 1960's. When a complex product is "modularized" it is in reality split into several components and then these components are assigned to modules in a specific architecture or plan. A complex system can be divided into smaller, less complicated modules which will decrease the entire systems level of complexity. Modularity in an engineering perspective is generally used for three main purposes (Baldwin and Clark, 2004):

1. To make complexity manageable
2. To enable parallel work
3. To accommodate for future uncertainties

Modularity can accommodate for future uncertainties because modular design allows for specific parts or modules of the design to simply be re-placed or changed without causing ripple effects to rest of the design. This does require some consistency in the methodology or design rules so that new modules can interact with the old design. This allows for new and better modules to be substituted with old modules simply and at low cost. Having the opportunity to simply exchange equipment modules may also increase flexibility.

There has been a continuously development within modular design and many industries has found modularity to be very beneficial in the production phase. The general approach of modularity is to shift the freeze point[1] to as late as possible in the production. Thus offering high product variety and while maintaining mass production as long as possible. This allows the companies to offer a wide range of products to the customer, as well as maintaining simple and standardized production and at low cost (Bertram, 2005). Several industries have adopted modular approach in their design methods, the most forthcoming are, amongst other, the automobile (VW, BMW, etc.) industry and the computer industry (Microsoft, Apple, etc.) (Hölttä-Otto, 2005).

The ship building industry has been somewhat more conservative and modular approach seems to have huge potential in this segment. Modularity can also contribute to increasing operational flexibility on vessels.

3.1 Modularization in Different Phases of a Vessels Life Cycle

Modularization has the possibility to improve many phases of a vessels life cycle. In this chapter are modularization and arguments on how modularization can have a positive influence in the three phases of a vessels life cycle; the design, construction and operation phase presented.

3.1.1 Design

Allowing the use of modularization can have a positive impact on many levels within the design phase. Correct implementation can contribute to a reduction in lead time in the design phase, which is very desirable. Module based design can also allow the designer to quickly reassess the design to provide new suitable solutions to the customer in a short amount of time. As a result of this designers can offer a higher variety in the design and produce new designs at a higher paste then before and thus increasing the number of projects and also increasing the income.

Modularization allows for higher creativity and most of all higher flexibility in the design. But at the same time modularization can also be a limiting factor with regards to

[1] The point in the production phase where product variety is introduced.

creativity if it constrains the designer to a set of specific modules and interfaces. It can be said that creativity can from one point of view be motivated by modularization, but from the other side modularization can also restrain creativity.

3.1.2 CONSTRUCTION

It is in the construction phase that modularization has had its highest effect up to now. The introduction of modularization in the production and also the introduction of separate production lines have increased the efficiency at production facilities. This has been in use for many years and has proven its positive effect on the production. Standardizing the modules and the interface between them can also reduce engineering and installation effort and time required in the production which also has positive effects in the construction phase.

To maintain high efficiency at yard facilities it is important that major bottlenecks are avoided. Bottlenecks are areas in the production line where it builds up a queue due to long installation time for some modules. Bottlenecks are major contributors to ineffective work and long waiting hours. Introducing separate production lines can contribute to eliminate some of the bottlenecks and in that way increase the total efficiency of the yard. Separate production lines are made possible from modularization; building blocks are constructed individually and assembled on the vessel at the most suitable time so that bottlenecks are avoided.

3.1.3 OPERATION

The operation phase may be the phase where modularization has had least impact yet. That does not need to imply that modularization is not useful in this phase, only that it is not taken fully advantage of yet.

Maybe the biggest advantage of introducing modularity in the operation phase is increasing flexibility, opening for a wider range of operations for each vessel. When the operational equipment is designed in a modular matter it becomes simpler to exchange or swap the modules in order to carry out different operations. This also has spin-off effects to service and maintenance of these equipment modules as service and repair can be done on shore and at the same time the ship can operate with other modules.

A growing trend today is building multi-purpose vessels. These vessels have a lower mission-specific efficiency then conventional one mission vessels. Low mission-specific efficiency implies that the vessel is not perfectly suited for one mission, which may limit the quality and ability to perform the operations. There is a trade-off between the ability to perform one operation and offering several types of operations. A vessel with modular capabilities will have the possibility of performing several operations without reducing the mission-specific efficiency.

When using standardized modules with common interface the possibility for exchanging modules becomes easier and the cost of offering and maintaining modules with state of the art technology and quality is reduced. Many ship owners wish to upgrade the vessel at some point of the operational life span and by building the vessel with a modular approach this upgrade can be simplified, especially with regards to new equipment modules and operation capabilities.

3.2 Modular Typology

Modular capabilities or mission modularity refers to a modular approach in the operational phase. In this report modular capabilities will be used when addressing this concept. Modular capabilities define a modularization of capability specific equipment so that the modules can simply and rapidly be exchanged for other modules in order to change either the overall capabilities or minor capabilities of the vessel. There are several different approaches for the implementation of mission modularity on vessels and can in general terms can be summarized as the following three different types.

- TYPE 1: Modular containers or other modular installation. Plug and Play modules with standardized interface and minimal installation time.
- TYPE 2: Modular installation. Also Plug and Play modules, but with significant longer installation time than for type 1.
- TYPE 3: Modular space utilization. Utilizing space potential which normally is reserved for other capabilities. For example: Remotely operated vehicle (ROV) hangar used for storage area for diver equipment.

Several concepts has already started embracing modularity in the operation phase and by using these types of modularity developed concepts to increase operational flexibility. For a better understanding of these three types of modularity and the concept which they are introduced in there are given a short review of their application in existing concepts.

4 Survey of Modular Technology in Ship Design and Operation

Navies around the world has been demanding methods for decreasing the fleet while at the same time being able to offer a wider range of capabilities (Glanville, 2010). In cooperation with actors in the shipbuilding industry the navies have been developing concepts for the implementation of modular ship design and with modular capabilities. This chapter gives a survey of those concepts where modular approaches with regards to enhanced flexibility on offshore support vessels (OSV) are most forthcoming.

The type of modularity that is used in the different concepts is given in each headline.

4.1 Standard Flex (TYPE 1)

The Standard Flex concept is one of the most forthcoming concepts within modular design. The concept is based on a standard hull platform and with different weapons and system modules to develop a multi-role vessel. The modules are based on containerized systems, making each module very flexible in when and where they are used. The concept allows the vessel to quickly alternate between different capabilities by simply swapping the equipment modules.

The Standard Flex design was first introduced in 1987 on the "Flyvefisken class" also known as the Standard Flex 300 and the methodology is still used on all new vessels in the Royal Danish Navy (RDN). The Flyvefisken class has 4 different positions where the modules can be installed. With these modular capabilities the Flyvefisken class can conduct several different operations such as surveillance, surface combat, anti-submarine warfare etc. Another benefit with the Standard Flex concept is that a vessel can convert to a different operation in very little amount of time and that new modules can be introduced without significant reconstruction of the hull. The conversion time is not to exceed 8 hours and requires only one crane to lift the modules in place. (Naval Team Denmark, 2012)

Figure 4-1 below illustrates the standard flex concept on the Flyvefisken class.

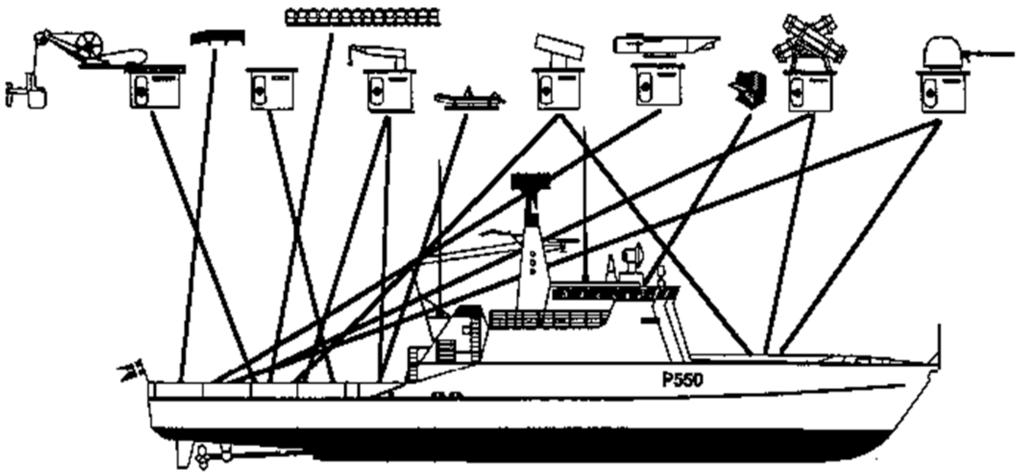

Figure 4-1 The Standard Flex concept

Since the introduction of the concept has all new classes built for the RDN been implemented with the same modular approach and module interface. Therefore RDN possesses a great amount of different modules which can be used on any ship in their fleet. (Naval Team Denmark, 2012).

Due to the modular outfitting the Flyvefisken class needed only 14 vessels to replace the existing 22 vessels operating at the time. Thus proving that with modular capabilities it is possible to reduce the fleet size without limiting the operational performance and the flexibility of the fleet.

The French navy has in collaboration with the Italian navy developed design for new frigates based on the Standard Flex concept. The modular design approach is used to provide desired flexibility and cost effectiveness. The concept should also make it easier to integrate new system development on the existing fleet (Bertram, 2005).

4.2 MEKO Blohm & Voss (TYPE 1 and 2)

"Mehrzweck-Kombination" (MEKO English: multi-purpose combination) are a modular design concept based on modularity of armament, electronics and other equipment on the vessel. The concept has existed for over 30 years and has had an ongoing process of development within the three design drivers; modularity, improvement in survivability and signature reduction (MacKenzie and Tuteja, 2006). The concept is developed by the German company Blohm & Voss and the intention was mainly to reduce maintenance and costs and at the same time offer variable and customizable outfitting on the vessel platform (Glanville, 2010).

MEKO design focuses on the weapon modules, electronics and the ships technical equipment. All the components needed to run the specific system are located in the one module and there is a standard interface delivering power supply, air conditioning and data supply. Figure 4-2 shows how the MEKO concept is implemented on the vessel.

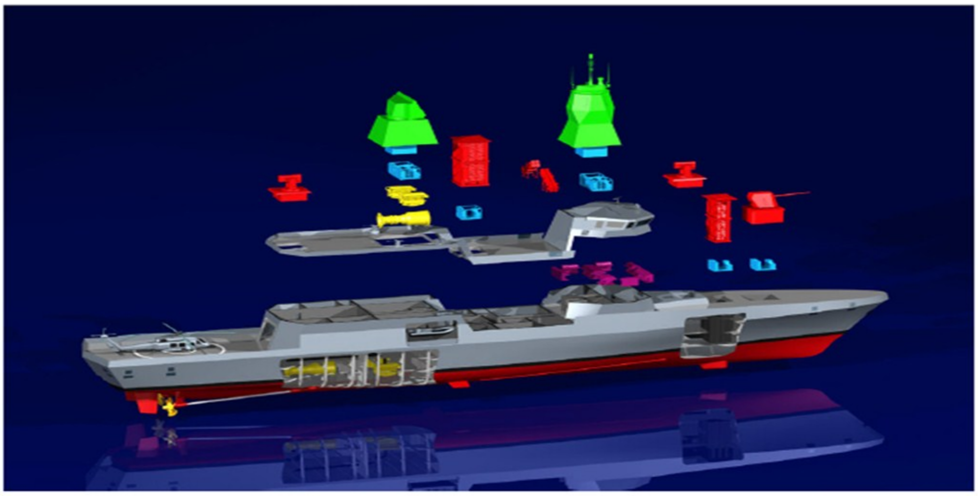

Figure 4-2 The MEKO concept

Despite the modular approach in the design and production phase of the MEKO ships there is little evidence of modularity being used in the operation of the ships today (MacKenzie and Tuteja, 2006). The reason for this might be that reducing build time and cost have been some of the main drivers for the MECO concept and not achieving higher flexibility from the modular approach as done in Standard Flex. This does of course not mean that it is not possible or beneficial to use modular design to increase flexibility.

4.3 MOPCO Abeking and Rasmussen (TYPE 2)

The modular platform concept (MOPCO) is another German concept. It is developed by the German shipyard Abeking & Rasmussen. The concept was introduced in the 1980's when a replacement program of German mine-counter vessels began. The MOPCO concept combines elements from both the standard flex and the MEKO concept (Glanville, 2010). The Concept is based on strict modularization of entire ship systems such as accommodation, bridge, armament etc. The modules contain all required equipment in order to fulfill the intended capability or task similar to the MEKO concept.

The MOPCO concept also relies on also standard interface between the various task modules/equipment modules and deck outfitting such as winches and cranes (Bertram, 2005).

Figure 4-3 shows a 45 meter long MCM (Mine Countermeasure) vessel where the MOPCO design is implemented. The left part of the figure shows how the vessel consists of its hull and the four main modules. This case is designed on a standard small waterplane area twin hull (SWATH) platform, but there is none limitations on implementing the concept on monohulls as is shown on the right side of Figure 4-3.

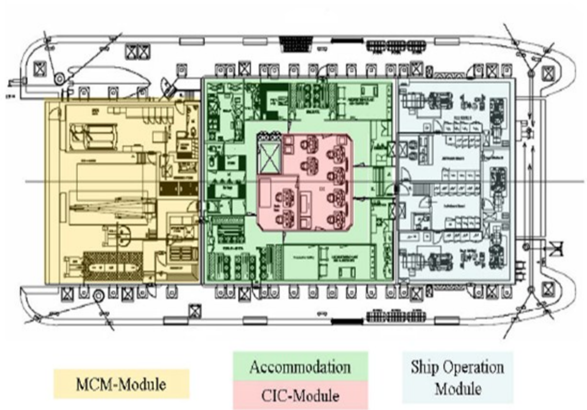

Figure 4-3 MOPCO concept on SWATH MCM and on a monohull (Glanville, 2010)

4.4 BMT VENATOR (TYPE 3)

The Venator concept is designed for small surface combatant vessels configured for several modular capabilities. These capabilities are today MCM, maritime security, hydrographic and environmental assessment and patrol missions. The Venator concept is based on a reconfigurable module to provide for the specific mission capabilities. The concept requires a large hangar or garage on the vessel. Figure 4-4 shows the characteristic arrangement of a vessel incorporated with the Venator concept. The light blue area (the garage, reconfigurable mission space, operations space) defines the reconfigurable modules. From this "garage" the vessel stores and operates the required mission modules, which can easily be substituted if requiring other mission capabilities.

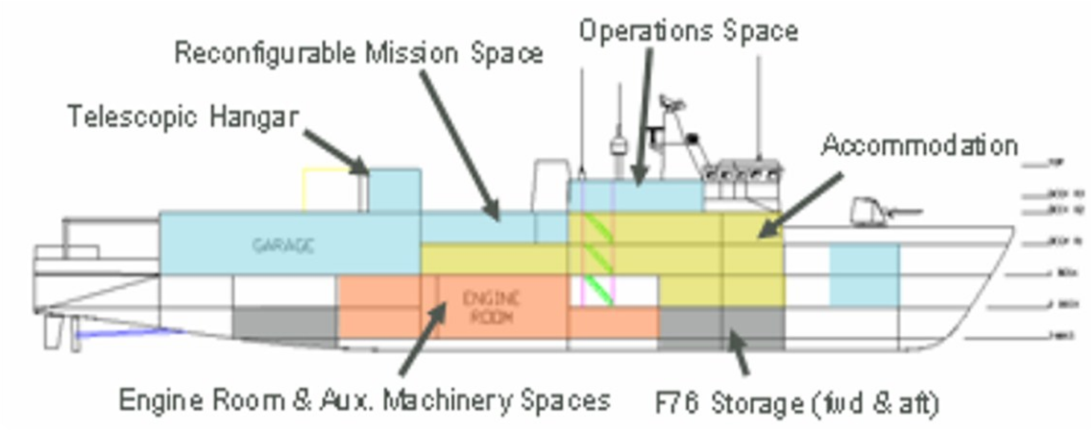

Figure 4-4 The BMT Venator concept (Kimber and Gales, 2008)

Along with this concept there are also recognized some challenges like assessing the size required for the various payloads and assessing the seaworthiness issues and sufficient size for longer endurance.

4.5 Ulstein Modular Design Strategy (Ulstein AS, 2002)

Late 2002 Ulstein launched an offshore supply vessel that was built by using the Ulstein Modular Design Strategy (MDS). The Vice President of Ulstein Yard AS describes the project as a first step in using a modular design philosophy to build OSV's.

The MDS uses standardization of building blocks to reduce manufacturing costs and to preserve high flexibility to the customer.

- *The whole idea of modular design is to find production-friendly solutions, in which the core concept is the reuse of ship modules, blocks and details. The shipyard develops standardized components that can be employed in flexible design solutions. This saves engineering and construction time*.

The Ulstein concept is a good example of how modularity can be used in the manufacturing phase, but it still lacks the possibility of offering flexibility to the customer in the operational phase. This is although a good step towards modular capabilities on offshore support vessels.

5 State of the Art Technology Summary

Table 5-1 summarizes the most promising concepts on the market today. Modular ship building and modular capabilities are, as Table 5-1 shows, more common within navy vessel than any other types, especially with regard to modular capabilities. The reason for this may be that the equipment modules defining the different operations for navy vessels are more similar to each other and smaller in size compared to equipment modules used on for example offshore support vessels.

However many of the concepts claim that one advantage of the concepts are increased flexibility with modular capabilities, even though it is still little evidence of vessels exploiting this advantage in operation. The exceptions are the Standard flex and (if successful) the littoral combat ship that are utilizing this advantage. One of the reasons that the Standard Flex concept is successful with regards to modular capabilities might be the standardized slots which all modules fit. This makes it very simple to swap modules without larger re-construction.

The majorities of the concepts are limiting the use of modularity to the construction phase and also to some degree prepare for a future re-conversion of the vessels to allow for other capabilities and modernization of the equipment. The known benefits that follow from introducing modularity in the design and construction phase are a reduction in design and construction cost and time as well as a higher product variety of different onboard systems and equipment outfitting.

Source	Type	Target	Objective	Application
(Naval Team Denmark, 2012)	Standard Flex	Navy	Increase flexibility, Fleet reduction.	Operation
(MacKenzie and Tuteja, 2006)	MEKO	Navy	Increase opportunities in onboard systems in design, Cost reduction in building, Improvement in survivability.	Construction/ Operation
(Bertram, 2005)	MOPCO	Navy	Increase flexibility in design and operation Cost reduction in building	Construction/ Operation
(Kimber and Gales, 2008)	BMT Venator	Navy	Increase operational flexibility.	Operation
(Ulstein AS, 2002)	Ulstein MDS	OSV	Increase flexibility in design, Reduce design and construction cost and time.	Construction
Other concepts not mentioned in the report, but equally important				
(Mahon, 2009)	Littoral Combat Ship	Navy	Flexibility in operation with modular capabilities	Operation
(Bertram, 2005)	Sigma	Navy	Increase flexibility in design. Reduce design and construction cost and time. Designing for tomorrows changes.	Construction

Table 5-1 State of art technology summary

The knowledge within modularization of vessels is increasing both in eyes of production and in operation, at the same time the industry is opening for the idea of modular vessels with modular capabilities. Modular concepts are proven to be beneficial for the navy and it should therefore not go unconsidered on offshore support vessels as well.

PART II –MODULAR CAPABILITIES CONCEPT

This part of the MSc thesis considers modular concept on offshore support vessels with high focus on utilizing modular capabilities. The part is split into two sections whereas the first section provides a study of various advantages and disadvantages recognized with modular capabilities on OSV's and also a concept evaluation based on the findings in the first chapters.

The second section is a comparison of the modular capabilities concept against multi-purpose OSV's and conventional mission specific OSV's.

6 Market Outlook for Offshore Support Vessels

The OSV market has been dominated by an overhang of tonnage that has been ordered prior to the financial crises in 2008. But from 2010 there have been seen bright spots in the market and the industry is slowly starting to grow again. In 2010 the growth of AHTS and PSV's where respectively 15 and 11 percent growth and is expected to sink to 3 and 6 percent in 2012 (Ziegler, 2011) leading to an increase in demand for the existing vessels. The reduction in growth may increase the competition between the designers and the customers. To win contracts the designers and shipbuilders must be able to deliver state of the art technology, opening for innovative designs.

New standards on greener shipping and the rapid introduction of more emission control areas (ECA) are also factors contributing to the demand of a newer and greener fleet.

It is a clear trend in the market that the future operations are moving towards deeper and harsher environments. This leads to higher requirements on the ship operations and design. It is recognized a demand in deepwater anchor handling, installation of subsea systems and ROV operations in deeper water and therefore requiring larger vessels, higher capacities, new equipment etc. (Vareide, 2011). These new requirements of capabilities and dimensions make it also difficult for old vessels to compete with newer, more advanced vessels. Mid-life upgrades of older vessels are often difficult and can involve high costs compared to new buildings. These trends open for new vessels to enter the market with success and where modular capabilities can be favorable.

7 Advantages and Disadvantages

7.1 Flexibility

Offshore support vessels that are built with high degree of equipment modularity have a great advantage by means of flexibility. There is no need to argue that one of the prime motivators for mission modularity is higher flexibility. For a ship owner it is important that all the vessels in the fleet are in operation at all time and for the oil companies it is important that there is a minimal waiting time for the right ship with the right capabilities to be available. Downtime[2] for both oil rigs and vessels comes with high costs and it is therefore crucial to avoid this. With modular capabilities on the vessels it gives the ship owner the possibility of offering a correct vessel with the correct capabilities at almost all time.

There is also reason to believe that a vessel with modular capabilities can provide more customized solutions thus gaining a higher mission-specific efficiency (Erikstad, 2009), especially if compared with multi-purpose vessels. In comparison to conventional OSV

[2] The time which a vessel is prevented from operating as normal.

this effect does not come through since these vessels already are highly specialized and might have even higher mission-specific efficiency.

The Royal Danish Navy has used the Standard Flex concept on all their new vessels the past year, exceeding over 30 vessels and to utilize all these vessels they have a stock of over 100 modules spread over a dozen different types (Naval Team Denmark, 2012). This is a great reduction in the amount of modules and hulls that would be needed if an integral architecture[3] had been used to offer the same range of capabilities with the same amount of vessels. It is therefore reason to believe that modular capabilities will allow for a fleet reduction compared to conventional concepts and that the total amount of required equipment modules will decrease parallel with the reduction in fleet size.

There are today a rapid development the market and equipment technology, and this requires that vessels are able to keep up with the development in the technology regarding equipment and operations. An advantage with a vessel that has modular capabilities is that new equipment modules can, if they are built on a common interface, be installed on the vessel without large re-construction. A modular vessel is likely to be more receptive to new modules compared to a conventional older vessel.

7.2 Spot Utilization

The spot utilization factor for OSV's gives an indication of the demand for the different offshore support operations. A vessel with high utilization has minimal downtime due to lack of contracts. Low utilization can be the result of many different reasons i.e. excess of similar vessels at the time or harsh weather conditions preventing vessels from operating etc. Spot utilization and spot prices are often varying equally meaning that a low utilization often results in a decrease in the spot prices.

Spot utilization does not necessary vary equally between the operations which a vessel with modular capabilities have the possibility to exploit. If for example the spot utilization is low for construction vessels and many of these vessels are not in use, it can be favorable to convert to other operations where the utilization is higher and the vessel is then more likely to receive new contracts.

Figure 7-1 represents the spot utilization of AHTS (Anchor handling, towing and support) and PSV (Platform support vessel) vessels in the North Sea in 2011. The data is collected from Hagland Offshore (Hagland Offshore, 2012) a Norwegian ship broking company.

The horizontal axes are weeks through the year starting in January. The vertical axes are percentage utilization of the vessels.

[3] Type of product architecture with high and complex interactions between modules. Integral architecture has few independent modules and functions.

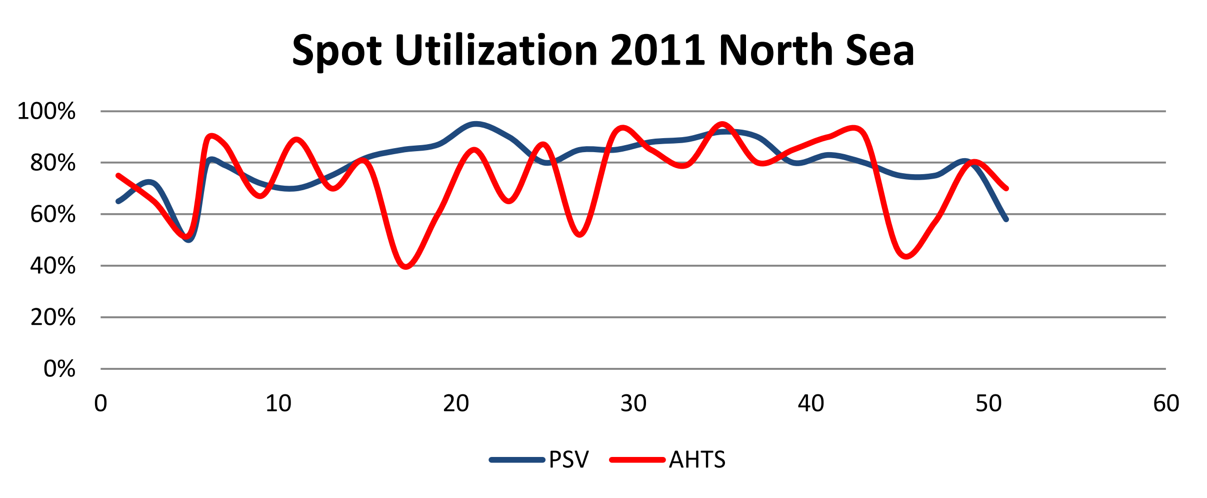

Figure 7-1 Spot utilization in 2011 for PSV and AHTS

Anchor handlers have a much more uncertain spot utilization, with higher variations compared to PSV's. AHTS utilization peaks on 95 % in week 35 and reaches ultimate low utilization in week 17 with only 40 %. For PSV's the utilization is more stable averaging around 80 % with peak on 95 % in week 21 and ultimate low in week 5 with 52 % utilization.

More importantly is the variation between the two vessels and in 2011 there were two distinct periods were the utilization rate for PSV were distinctively higher than for AHTS. The two periods lasted from week 15 to 29 and week 45 to 49. The last period might have been too short for a possible re conversion to be beneficial, but the first period lasts for over 13 weeks, and should give enough time to reconstruct the vessel and perform operations before the utilization rate increases again for anchor handling vessels. In this period it can be beneficial to convert the vessel, especially when the utilization rate decreases to as low as 40 %.

The problem with spot utilization is that predicting utilization rates in the time coming is very difficult and can in fact be compared to predicting the weather, you can have many theories and models on how to predict tomorrow's weather, but there is none definitive way to determine the weather for tomorrow, especially over longer periods in harsh environments. It doesn't help that you predicted the spot utilization to sink rapidly it the fact is that it still is growing the day after.

Benefiting from variations in spot utilization has two main criterions;

1. Distinct variations in the spot utilization from the different vessels and preferably a method to predict that the trend in variation will last for a longer period.
2. Short time to re-convert the vessel between operations too quickly benefit from the variations and in case of unexpected changes in the spot utilization favoring other operations again.

7.3 Environmental Perspective

The past decades there has been an increasing attention towards the environmental impacts of air and sea caused by sea transport and operations. In the time coming environmental issues will have even greater influence on the ship owners and builders. The International Maritime Organization (IMO) has introduced requirements to reduce emissions and placing high emphasis in coastal areas (Emission Control Areas, ECA) including the North Sea (A. P. Moller - Maersk Vessels, 2007) which is affecting new building OSV's intended to operate in these areas. The consequences so far for reduced emissions and increased sustainability has been increased cost for ship owners in form of higher building and operating cost, higher equipment cost etc. in order to accommodate for the new requirements set to reduce emissions. (Ulstein AS, 2009).

Within the concept of modular capabilities and environmental perspective is the issue if operational modularity can contribute to increased sustainability and higher energy efficiency for the environment?

The IMO regulations for ECA areas and in general have limited constraints regarding the operation functions of the vessels. The regulations focuses more on reductions from the machinery, fuel, fouling etc. thus there are little or none difference between a conventional vessel and a modular vessel in this matter since the vessels will most likely have the same types of engines, fuel etc.

There are little obvious coherence between modularization and increased sustainability and energy efficiency (Erikstad, 2009). This especially if only considering equipment modularity and modular capabilities instead of modularization in design and building. But there are some factors that can effect emissions and sustainability indirect from modularity.

- Modular capabilities can lead to an overall fleet reduction which again might lead to less emission and higher energy efficiency both in the construction and operation phase.
- Modular capabilities can increase mission-specific efficiency and thus decreasing operation time leading to lower emissions and higher energy efficiency.
- Modular capabilities requires at some degree a larger vessel then conventional OSV's. This has spin-off effects to resistance, machinery etc. that increases emissions both in operation and building.
- Increased transportation of vessel and modules to swap equipment modules can lead to more emission than with conventional and multi-purpose vessels.

Without further and more thorough research it is impossible to definite determine whether or not modular capabilities can contribute to emission reduction. There are factors giving modular capabilities both positive and negative impact in an environmental perspective. The most important to establish is that there are elements arguing that modular capabilities can contribute to emission reduction and that there are reason to continue the research within this field.

7.4 Challenges with Equipment Modularity

Modularity comes with many advantages, but with advantages there are always dis-advantages. This chapter gives an overview of some of the drawbacks that can be recognized with the concept in regards to equipment modularity on OSV's.

In this report there has been strong emphasis on a possible fleet reduction as a result of the modular capabilities. The Danish StanFlex concept was able to replace a fleet of 22 vessels with only 16 vessels (Wikipedia, 2012) showing that a fleet reduction is possible. But as the market continuous to grow there will always be a need of different sets of operations and since no vessel can be at two different positions at the same time there will always be a need of equally amount of vessels as there is operations. It must therefore be considered at which extent it is eligible to reduce the fleet and at the same time meet the demand from the market.

Maintaining the use of modular capabilities can be a challenge. Designing and building a vessel intended to operate as a modular vessel will lose its advantages and benefits if it in the long run becomes a multi-purpose vessel with all equipment modules installed. For example is the MEKO concept were the vessels are modular in design and production, but there are little evidence of the vessels operating with modular capabilities. It is therefore important to place high emphasis on constructing/designing the modules so that they are simple and efficient to handle in a conversion. The faster and simpler a conversion can be done, the more plausible is it that the concept will become profitable.

The flexibility in modular capabilities demands a dimensioning of the vessel for the highest requirements from the different modules. This over dimensioning can cause unnecessary emissions as described previously.

When building with regards to modular capabilities the vessels standard platform must be of adequate strength and size to carry out the most "demanding" operation with regards to hull strength, stability, main dimensions etc. Meaning that the vessel must be dimensioned for a "worst case scenario" and it will therefore be over dimensioned with regards to size and weight in operations not having the same requirements. A conventional vessel with integral architecture performing the same operation will most likely be more energy efficient (Erikstad, 2009) compared to a vessel with modular capabilities.

A great challenge with equipment modularity on OSV's is the complex equipment. The majority of concepts using equipment modularity use containerized modules where the interface is simple and standardized i.e. Standard flex and MOPCO concept. Unfortunately due to the level of complexity on the equipment modules required for offshore operations it becomes difficult to find a simple and standardized interface that can be used on the modules. The complexity of the equipment modules on OSV's also makes them strict dependent of their location on the vessel. The modules are not capable to perform its task if it is located wrong. Thus becoming difficult to establish a standard interface and swapping modules with each other. If a module is to be removed there is no module that can operate at the same location resulting in an open and unused location. It is therefore necessary to find a solution to make the space operational again.

The level high level of module complexity also affects the port facilities. Port facilities must have necessary infrastructure, technology and equipment so that they are capable of handling and reconstructing the modules on the vessel under a conversion. Port facilities must also have sufficient storage room where modules can be stored when not in use.

Another challenge that follows with high flexibility is maintaining qualified personnel at all times. This is a challenge that has effects on both modular vessels and multi-purpose vessels. On conventional vessels the crew is only needed to perform one specific operation, but since modular and multi-purpose vessels perform a set of different operations the working personnel must be able to conduct all these different operations. To solve this challenge there are generally two different approaches, invest in extensive training for the crew so that they can perform all duties onboard or the personnel can rotate when the vessel change operations. When using crew rotation there is a high risk of having excessive personnel on shore resulting in high costs. There has to be a trade-off between the cost of training personnel and the risk of at times having excessive personnel. There is also reason to believe that more training and higher variation in work tasks can be motivating for the crew and therefor increasing their efficiency and morale.

8 COST

When determining the feasibility for a new concept it is very import to evaluate the costs that are related to the concept. In this chapter a cost assessment has been done from two different aspects. One aspect is the operational phase, where the costs have been discussed from the influence on day rates compared to conventional vessels. The other aspect, equally important, is predicting the costs of a conversion between operations which will be essential for maintaining modular capabilities.

8.1 MODULAR VESSELS INFLUENCE ON DAY RATES

Following is an assessment of different costs related to a modular concept in the operation phase and how they will effect in both a short and long term perspective. Short term perspective reflects only implementation of the concept on one or few ships while it in a long term perspective a whole fleet of vessels will be considered. The reason for an approach from two different perspectives is that there is a strong reason to believe that the costs within the respective perspectives will be very different.

Operators are mostly concerned about the day rate and tend to choose the vessels that offer the lowest day rate with the lowest acceptable standard (Hovland and Gudmestad, 2008). A conservative estimate of the anticipated day rate for vessels implemented with the modular concept is therefore valuable in the concept evaluation.

Day-Rate Division(north sea operation)	Larger PSV w/Moonpool and ROV
Vessel capital and operating cost [%]	36,7
Equipment capital and rental cost [%]	10,1
Personnel [%]	33,2
Overheads, contingency etc. [%]	20
Total	100

Table 8-1 Day rate for Conventional PSV (Hovland and Gudmestad, 2008)

Table 8-1 shows the day rate for an existing vessel broken into 4 different categories. The vessel is a large, specialized IMR (Inspection, Maintenance and Repair) vessel with moonpool and ROV Launch and Recovery, based on an operation in the North Sea. This vessel is set as the basis for the comparison.

Table 8-2 shows the guesstimated change of the four categories for a modular vessel performing the same operations.

Day-Rate Division	Modular OSV - Short term	
Vessel capital and operating cost [%]	Increase	10 %
Equipment capital and rental cost [%]	Increase	10 %
Personnel [%]	Increase	15 %
Overheads, contingency etc. [%]	Equal	0 %
	Percentage change in total day rate	**9,66**

Table 8-2 Anticipated change in day rate for modular OSV

In a short term perspective it is likely that there is a distinct increase in all categories. The vessel will have higher building costs because of a more complex structure and an over dimensioning in order to perform several capabilities. This over dimensioning also has spin-off effects to the operations, mainly in form of higher fuel consumption due to added weight and resistance. Investing in one vessel will also give high cost in regards to the equipment. In order to have an advantage of the modular capabilities the vessel must have a stock of several different modules so that it can perform all operations. The investment of all these equipment modules will affect the day rate and cause it to increase. The vessel is intended to perform a set of different operations and requires therefore personnel that can perform all these duties. This can be solved by extensive training of personnel or having personnel on rotation. Independent on which solution that is chosen will it cause an increase in the cost.

There is not anticipated an increase in the cost of overheads, contingency etc.

To summarize the cost effects on a short term perspective there will be a significant increase in the cost. Assuming an increase of 10 percent in vessel capital and operating cost and for equipment, as well 15 percentage increase for personnel we see that the total increase in day rate are close to 10 %. This increase will add up to very high numbers when calculating over one or more years and are not beneficial for any ship owner or the operator companies.

Reviewing the same costs from a long term perspective has a quite different outcome. On a longer perspective it is reasonable to assume that the concept has successfully entered the market and the ship owner now has a larger fleet of vessels with modular capabilities. Thus there is no longer a need for as many vessels as before due to the flexibility of the new vessels, causing a reduction in the vessel capital and operating costs. This fleet reduction will also reduce the number of required equipment modules compared to a conventional fleet. Since excessive equipment modules are stored at shore personnel can perform maintenance and repairs on the module without causing downtime on the vessel and therefore increase the efficiency

The personnel cost in a long term perspective are not expected to vary much from the estimate from the short term perspective. Training cost might be reduced somewhat due to more efficient training and that the demand for personnel will stabilize itself at some point.

There is anticipated a minor decrease in overheads and contingency etc. due to a decrease in the total amount of vessels in the fleet.

Table 8-3 shows the anticipated change in the day rate for a modular vessel in a long term perspective.

Day-Rate Division	**Modular OSV - Long term**	
Vessel capital and operating cost [%]	Decrease	-10 %
Equipment capital and rental cost [%]	Decrease	-10 %
Personnel [%]	Increase	7 %
Overheads, contingency etc. [%]	Decrease	-4 %
	Percentage change in total day rate	**-3,156**

Table 8-3 Anticipated change in the day rate, long term perspective

We see from that a conservative estimation of the expenditures in relation to the day rate will with a fleet of modular vessels decrease with 3 % compared to the conventional PSV day rate in Table 8-1. The precise reduction in the day rate is of course only an estimate, but what is important is that there will most likely, with this scenario, be a prospective reduction in expenses compared to conventional vessels if modular capabilities are implemented.

8.2 Conversion Costs

One of the biggest factors left out of the previous calculation is the conversion cost. Depending on module size and the system interface this can be a relatively high cost for each conversion. There are in general three cost factors associated with the conversion.

1. Expenses associated with the yard. These include, but not limited to, quay services, crane services, personnel and equipment costs at yard.
2. Loss of income. When the vessel is being reconstructed it is not possible to perform operations and has therefor a loss in income. This loss in income increases along with the reconstruction phase.
3. Logistics cost. These costs are related to the vessel transport to and from operation area for the conversion. There can also be cost associated with preparing/transporting the equipment modules for installation on the vessel.

To reduce this cost there must be placed emphasis on simplifying the modules interface so that the installation complexity and time are reduced.

The income for OSV's is either based on spot prices or contract prices. These prices tend to vary very from day to day and moth to month depending on availability, weather conditions, vessel capabilities etc. The advantage of a modular vessel is that it can at any time convert to different operation and therefor utilizing the highest day rates on the market at the time. In order to do this the ship owner has to calculate the cost of a possible conversion against the increased income of a higher spot price.

8.3 Predicting Conversion Cost and Profit

It is important to confirm increased revenue of a conversion before it can be done. I will in this chapter present a mathematical model and the driving factors to determine the possibility of a conversion for a vessel. Many of these costs are very time dependent and it is therefore more accurate to divide the costs within different periods. Especially with costs or incomes that vary with spot prices or fuel prices.

Equation 1 calculates the revenue for any vessel over any given period. The revenue is based on two parts. These are the income from operations and the off hire cost for the vessel if there are periods without a contract. The off hire costs are the bear minimum costs of operating the vessel at standby. To account for variations in spot price the spot price income and off-hire costs are calculated over different time periods.

$$R = \sum_{i=1}^{n} \left(OD_i * SP_i \right) - \sum_{j=1}^{n} \left(D_{OH\,j} * C_{OH\,j} \right) \tag{1}$$

Where:

R	Revenue
OD_i	Days operating at spot price i
SP_i	Spot price at period i
$D_{OH\,j}$	Days off-hire in period j
$C_{OH\,j}$	Cost of off-hire in period j

If a conversion is done there are several different expenses that must be taken in consideration. These are transportation costs to and from yard, cost connected to yard services, equipment preparation costs etc. And these expenses may be calculated as in Equation 2. The equation is divided into three different categories; transportation cost, costs related to the yard services and the last is all costs associated with preparation of modules, vessel etc. The transit costs are also summed over periods due to variations in fuel price, transit time and fuel consumption. Fuel consumption and transit time may vary due to longer distance to and from the yard and heavier equipment which result in higher fuel consumption.

$$C_c = \sum_{i=1}^{n}(T_i * m_{fi} * Cf_i) + (F_c * (YD * C_Y)) + \sum C_E \qquad (2)$$

Where:

T_i	Transit time
m_{fi}	Fuel consumption at period i
Cf_i	Fuel cost in period i
F_c	Fixed costs from yard
YD	Days under construction at yard
C_Y	Costs of yard stay per day
C_E	Costs associated with equipment preperation before conversion

When these costs have been established the ship owner has good grounds for a decision regarding a possible conversion. But there is still one important factor that cannot be disregarded in this manner. That is the lost income which comes in the period from the vessel stops operating till it starts operating again, during transit, conversion etc. This period would have given income if the conversion was not done. It is not a direct cost but should be considered and taken account to when comparing the two different solutions. Equation 4 shows how the lost income can be determined. Once again the spot price may vary so the lost income is the sum of the periods of the conversion. If there are no great changes in spot prices the conversion period can be calculated as one.

$$LI = \sum_{i=1}^{n} SP_i * (T_i + YD_i) \tag{4}$$

Where:

LI	Lost income for conversion
SP_i	Spot price in period i
T_i	Transit days between operation and yard for conversion i
YD_i	Days spent at yard on conversion i

The total income, I_T will then is as given in Equation 5:

$$I_T = R - C_c - LI \tag{5}$$

A conversion of the vessel will be beneficial if the total income for the converted vessel exceeds the total income if not converted.

Any future variance of the spot prices has not been taken account for in this method, this is an important factor that can have great influence on the level of costs and will therefore be taken into consideration in the case study of the prediction costs to see how variances in day rates can affect the prospects of a future conversion.

8.3.1 Case study; Conversion cost and profit

Background: A vessel is today operating as anchor handler in the North-sea. The spot price is decreasing because a high availability of AHTS vessels. At the same time there is a distinct increase in the spot price for sub-sea construction operations and the ship owner wishes to utilize this. Since spot prices can be very uncertain, it is important that the payback period of the conversion is relatively short. The ship owner wishes to know if it is possible to exploit this situation and also approximately how long the payback period will be for the conversion.

There are in this case two different alternatives.

1. There is no conversion and the vessel continuous with AHTS operations. This is further referred to as operational profile 1 (OP1).
2. The vessel is transported to a yard and is converted to a construction support vessel (CSV). This is further referred two as operational profile 2 (OP2).

Calculations

Table 8-4 shows the input data that is used in the case study.

Case Input	Operation Profile 1	Operation Profile 2	
Day rate	22 000,00	58 000,00	[$]
Conversion time	2,50	2,50	[days]
Distance - Operation to Yard	2,00	2,00	[days]
Distance - Yard to Operation	2,00	2,00	[days]
Fuel consumption	18,00	18,00	[ton/day]
Quay services	100 000,00	100 000,00	[$/day]
Fixed quay services	10 000,00	10 000,00	[$]

Table 8-4 Input data for case study

The day rate has been collected from RS Platou (RS Platou, 2012), where upper and lower day rate at the moment (30.04.2012) was chosen. The standard flex concept described in chapter 4.1 can swap the equipment modules to change operation profile in any harbor with an crane in less than eight hours (Naval Team Denmark, 2012). The conversion of our vessel is expected to be much more complex, and is therefore guesstimated till 2.5 days. The distance is a hypothetical example and two days of transit should be a conservative estimate. The fuel consumption are based on findings in the report "An Activity-based Life-Cycle Assessment Method" (Emblemsvåg and Bras, 1997) and verified in vessel brochures by Rem Ship (Rem Ship AS, 2012). Total fuel costs are based on fuel consumption and the current price of marine diesel oil (MDO) for Northern Europe April 2012 (Bunker Index, 2012).

The revenue for the two alternatives is calculated from Equation 1 and is illustrated in Figure 8-1 and Figure 8-2. To simplify the calculations there has not been included any off hire days between contracts.

Table 8-5 shows the yard related costs based on the input data.

Yard costs		
Conversion time	2,50	[days]
Quay services	150 000,00	[$/day]
Fixed quay expenses	10 000,00	[$]
Total yard cost	**385 000,00**	[$]

Table 8-5 Calculated costs from yard stay

Quay services are costs that cover use of yard personnel and equipment, the port fee etc. The cost is set to be 150 000 USD per 24 hour. Fixed quay expenses are cost that is not increasing with the stay; this can typically be insurance etc. The fixed cost is estimated to be 10 000 USD. This gives us a total cost of 385 000 USD at the yard for the conversion itself.

Table 8-6 shows the calculation of the logistics cost related to the conversion.

Logistics cost		
Days Off-hire	6,50	[days]
Lost Income	143 000,00	[$]
Fuel consumption per day/transit	18,00	[ton/day]
MDO price	950,00	[$/ton]
Total transit cost	68 400,00	[$]
Equipment preparation	50 000,00	[$]
Total logistics cost	**261 400,00**	[$]

Table 8-6 Logistics cost

The biggest contribution to the logistics cost are the off hire cost. This loss of income is very important when comparing the two different alternatives. The total logistics cost including loss of income is 261 400 USD.

In total		
Yard costs	385 000,00	[$]
Logistics cost	261 400,00	[$]
Total cost to convert	**646 400,00**	**[$]**

Table 8-7 Total costs from conversion

Table 8-7 shows us the total cost of converting the vessel from AHTS to CSV. We can use this cost and the earnings from the two operation profiles to evaluate a possible conversion.

Figure 8-1 is a representation of the predicted income for the two different operation profiles over the next months based on Equation (1) and (5). For OP1 there are no conversion cost and the income is positive from day 1, for OP2 the conversion cost must be earned in before the company can withdraw profit, therefor are the income starting at minus 646 400 $, the price of the conversion. The horizontal axes are days in operation.

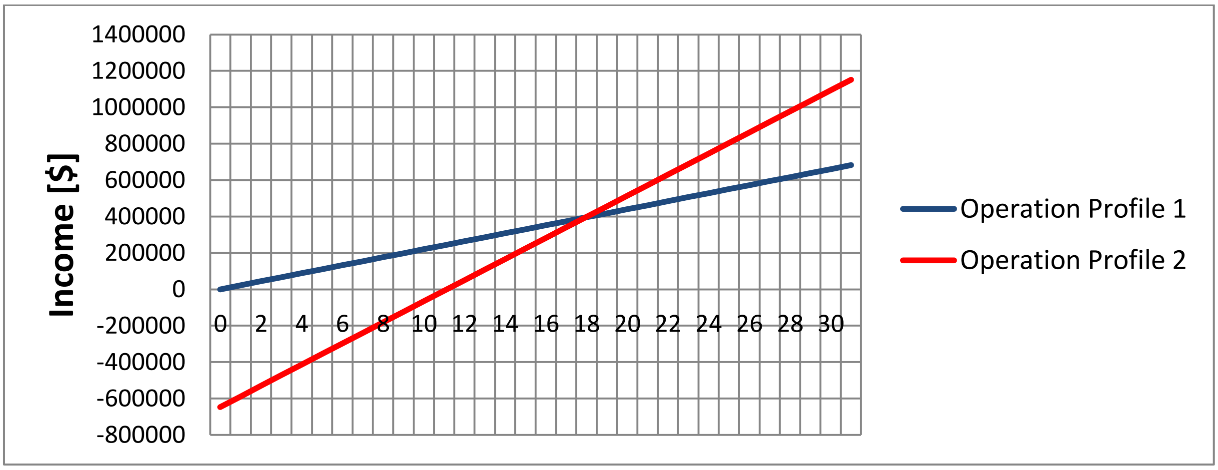

Figure 8-1 Predicted income of the two operation profiles incl. conversion costs

From the figure we find two especially interesting days. The break-even point[4] for this case is after 12 days. After 17 days the income of OP2 exceeds OP1 and the conversion has been beneficial.

Maybe one of the biggest challenges with this approximation is that it does not consider changes in the day rate over time. The spot prices can vary heavily and it is therefore very inaccurate to consider a fixed day rate over one month. Figure 8-2 shows a scenario where the spot price for OP1 increases with 30 % 10 days after an eventual conversion and the spot price for OP2 at the same time decreases with 30 %. The new spot prices for the two scenarios are respectively 28 600 USD and 40 600 USD.

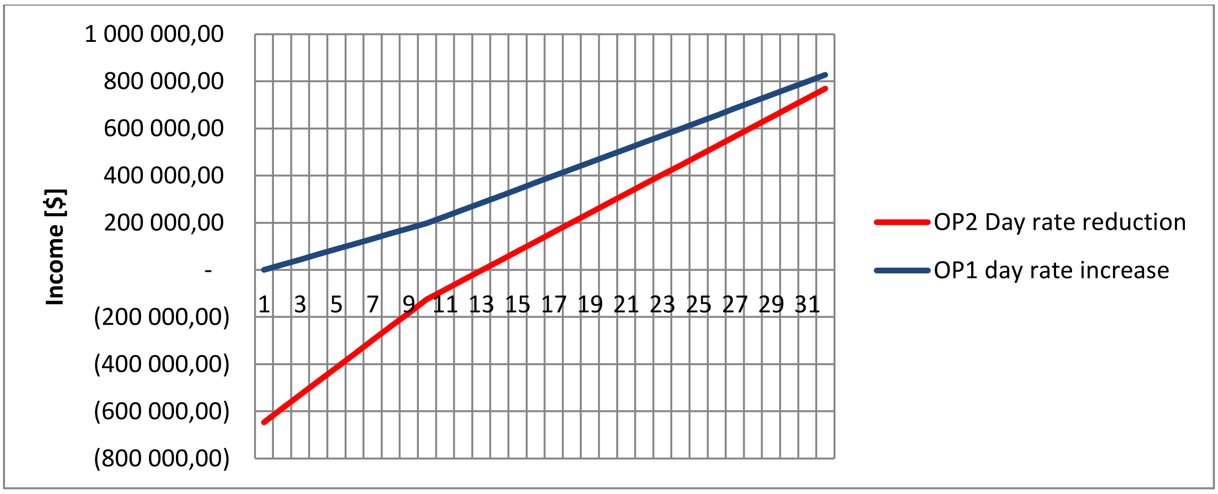

Figure 8-2 Predicted income of the two operation profiles with change in day rate

With the new day rates after we see that the break-even point are now after twelve days, approximately the same as before. More interesting we see that within this period of operating it does not become beneficial two convert the vessel to OP2. The difference in income after 31 days is 58 400 USD in favor OP1 and it is not before after 36 days of operation that OP2 becomes beneficial.

The ship owner has now more accurate data to determine whether a conversion will be beneficial or not.

Even though this is a hypothetical case and that the values used in the case are not validated in a real life situation we see that with the high day rates and the high differences in day rates there is reason to believe that it is possible to convert a vessel for other operations.

See Appendix I – Detailed Graph Data for Conversion for exact values used in the graphs earlier.

[4] The point where the costs from the conversion is paid back and the vessels has positive earnings again

9 Concept Evaluation Summary

The past chapters have given a review of the different advantages and dis advantages with modular capabilities and many of the challenges recognized with the concept of equipment modularity. Table 9-1 presents a summary of the different consequences following with a modular concept on offshore support vessels.

Attribute	Consequence	Effect (Positive/Negative)
Flexibility	Higher mission-specific efficiency	Positive
	Increased spot utilization	Positive
	Reduction in total fleet size and equipment modules.	Positive
	Reduction in fleet can reduce personnel and administration and relating	Positive
	Over dimensioning to fit all possible modules	Negative
Modular design	More receptive to new technology/modules	Positive
	Better designs, more options in the design phase.	Positive
	Complex mission specific modules, difficult to develop standardized interface.	Negative
Operation	Easier maintenance and service on shore. Less downtime.	Positive
Increased Costs	Higher costs related to yard services	Negative
	Higher cost of training personnel	Negative
	Logistics cost related to equipment modules e.g. transportation and storage.	Negative
Environmental	Reduced fleet.	Positive
	Higher utilization factor and decreased operational time.	Positive
	Larger vessels compared to conventional vessels gives higher emissions.	Negative
	Increased transportation between operations	Negative

Table 9-1 Concept evaluation summary

There are clear advantages with the concept related to flexibility, by offering more operations, increasing the spot utilization and the possible fleet reduction makes this concept very promising. Besides flexibility, modular design also has promising prospects in the design phase, opening for more options and flexibility in the design. Building a vessel on a modular platform also makes it more receptive for new technology and modules making it easier to keep up with tomorrow's challenges today.

The negative sides of the concept are difficult to pinpoint. Many of the consequences recognized with the concept are vague, meaning that they can have both negative and positive effect depending on the eyes evaluating. There are elements, especially in the cost category, which will need further and deeper investigation.

The main goal for introducing modular capabilities on offshore support vessels is to increase flexibility in the operations. The concept evaluation shows clear advantages and possibilities for increased flexibility. Thus there are reasons to continue the developing the concept for implementation on offshore support vessels. However it is important to remember that for a modular concept, such as this, to become successful it is important that the ship owner and customers have faith in the concept. Many of the advantages described will not appear before the concept has fully developed and the resources in form of more vessels and equipment modules are sufficient.

10 MODULAR CAPABILITIES COMPARED TO EXISTING CONCEPTS

Before it is possible to compare a vessel with modular capabilities with vessels from the modern fleet of offshore support vessels some assumptions of the modular vessel must be established. This is because vessels with modular capabilities are not yet built and therefore are a lack in knowledge on the vessels limiting the comparison. The assumptions that have been taken in the comparison study following:

- Modular capabilities on offshore support vessels are feasible and the vessels are utilizing the operational flexibility.
- A conversion between two operations is feasible and that the cost and time of a conversion are within reasonable limits.
- The costs of a conversion can be assumed to be earned back within short amount of time, making a conversion profitable relatively fast.
- The modular concept is based on a fleet of vessels so that the modular capabilities are fully exploited with regards to equipment modules etc.

The later year's ship owners and researchers have been driving forces for innovative design offering more flexible vessels, capable of performing a larger set of operations compared to the conventional vessels. This has led to the design of multi-purpose vessels. Multi-purpose vessels are recognized by their large size, high crane capacity, large accommodation and powerful machinery.

The multi-purpose vessels used for the basis for the comparison are the North Sea Giant from North Sea shipping and DOF Subsea's Skandi Skolten. The North Sea Giant was built in 2011 and is one of the newest multi-purpose vessels. The operational capabilities of the vessel range from cargo transportation to advanced subsea construction (North Sea AS, 2011). Skandi Skolten is a bit smaller than the North Sea

Giant, but can still perform a variety of operations including subsea installation, deepwater mooring and anchor handling (DOF Subsea, 2010). Figure 10-1 shows the multi-purpose vessel Skandi Skolten.

Figure 10-1 Multi-purpose vessel Skandi Skolten

Conventional vessels are smaller vessels with very high mission-specific performance and low flexibility. The vessels represening conventional vessels in this comparison is KL Saltfjord, a large anchorhandler delivered to “K” Line Offshore in 2010.

Even though specific vessels are used as underliynig basis for the comparison, has also the fleet in general been considered when evaluatind each attribute of the comparison.

The attributes chosen to represent the comparison study are based on both the concept evaluation done previously and attributes that are considered important for ship owners when investing in new vessels.

Table 10-1 describes the different attributes that has been chosen for the comparison study.

Attribute	Description
Build cost and time	Reflects building costs and the building time.
Mission-specific efficiency	Describes the vessels accuracy for the different operations, a high mission target performance is desirable.
Hull efficiency	Level of vessels volume utilization with regards to each operation.
Operational flexibility	Breadth of possible operations the vessels can perform.
Operational costs	Costs in association with the operation phases of the vessel.
Maintainability	Based on time and cost maintaining the vessel and equipment modules at a high standard.
Availability	To which level the ship owner can offer customers the right capabilities at the right time.
Mid-life upgrade and secondhand value	Preparedness for a future mid-life upgrade and the Prospects for a possible secondhand value.
Emissions	To which extent the concept contribute to emission reduction.

Table 10-1 Description of attributes used in the comparison study

Some of the attributes have already been cast light on previously under chapter 6 Advantages and Disadvantages and will therefore not be commented further in this chapter.

A vessel with modular capabilities will be larger and more complex than a conventional vessel and can also be believed to be more complex than multi-purpose vessels due to more complicated system installation and the preparedness for future module exchange.

The evaluation of the concepts can be found in Appendix II – Concept Comparison. The concepts are given a score between 1 and 3 in each category. Table 10-2 shows each category and the respective score for each concept.

	Modular OSV	Multi-purpose	Conventional
Build cost and time	1	2	3
Mission-specific efficiency	2	1	3
Hull efficiency	2	1	3
Operational flexibility	3	2	1
Operational costs	3	1	2
Maintainability	3	1	1
Availability	3	2	1
Mid-life upgrade	3	2	2
Emissions	3	2	2
Total:	23	14	18

Table 10-2 Comparison results of the three concepts

When the three concepts are compared under these categories it is clear that a vessel with modular capabilities is favorable over the other concepts. A result that might come from the fact that some of the categories the vessel concept are compared in are to slightly favoring a modular concept. To reduce this effect it is possible to introduce weighting factors on more important attributes.

The prime focus for ship owners is capital and there should therefore be placed higher emphasis on those categories affecting the costs e.g. build time and costs, operational costs, mission specific efficiency and hull efficiency. Mission specific efficiency is included because many ship owners do not wish to pay for exactly what they need at the time and not what they might need in the future. Table 10-3 shows the comparison with new weighting factors.

Weighting		**Modular OSV**	**Multi-purpose**	**Conventional**
2	Build cost and time	2	4	6
2	Mission-specific efficiency	4	2	6
2	Hull efficiency	4	2	6
1	Operational flexibility	3	2	1
2	Operational costs	6	2	4
1	Maintainability	3	1	1
1	Availability	3	2	1
1	Mid-life upgrade	3	2	2
1	Emissions	3	2	2
	Total:	31	19	29

Table 10-3 Comparison results of the three concepts with weighting

The result of the comparison is still favoring modular capabilities, but a conventional operation specific vessel is close behind. Since the modular capabilities concept and a conventional concept are almost equal it becomes difficult to conclude with which concept that is the better and a more accurate evaluation of each category, including a more thoroughly concept study of modular capabilities concept, should be carried out.

Result

Comparing a vessel with modular capabilities with conventional mission specific vessels or multi-purpose vessels is difficult. There are many reasons for this, but some more obvious than others. First of all even though the vessels perform the same operations are they not the same type of vessels. A modular vessel offers flexibility whilst a conventional vessel offers high mission specific efficiency with limited flexibility. It is therefore in the end more important what the customer requires; flexibility or high mission efficiency. Secondly there are many assumptions that are backing up the advantages and disadvantages of the modular capabilities concept which should be eliminated before the comparison is to be trustworthy. This being said it is still possible to learn from the comparison.

Following is the key findings from the comparison:

- Different weighting of factors can manipulate the results. The outcome of the comparison can to some degree be pre-determined and can therefore favor any concept.
- Modular OSV's offer high flexibility, but this comes at the price of hull efficiency, mission specific efficiency and also building time and costs.
- Multi-purpose vessels seem to come out in the losing end of almost every comparison. The reason for this can be that multi-purpose vessels falls in between the different concepts (flexible or target mission specific) and their benefits are not sufficient represented in the comparison.

PART III – METHODOLOGY AND CASE STUDY

This part gives a description of the basic steps of the methodology developed. The methodology creates the equipment structure for a vessel which is designed for operating with modular capabilities.

As a demonstration of the methodology a case study has been done. The case has its starting point from an outline specification as delivered from the ship owner to the designer.

11 MODEL

Figure 11-1 shows the steps of the methodology.

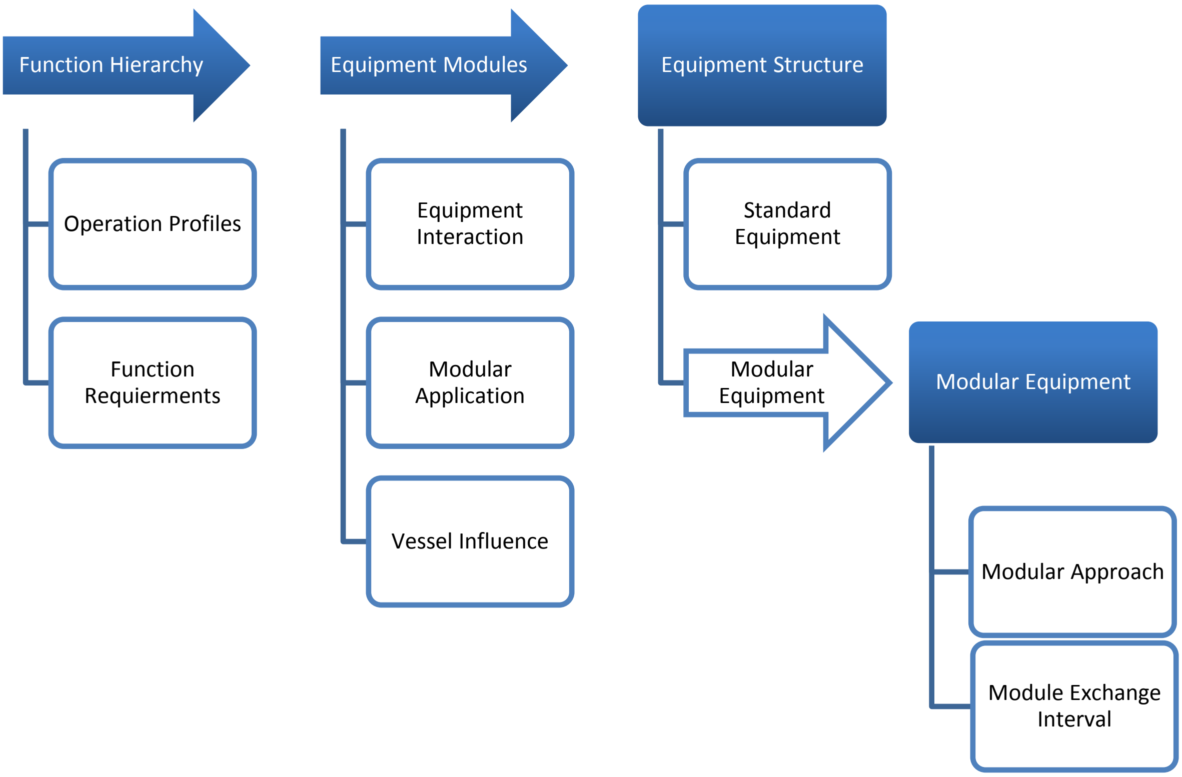

Figure 11-1 Model for equipment structure establishment

The model is a chart of the structured approach on how to find the equipment structure, modular approach of the equipment and most importantly their exchange interval. All the steps in the model from establishing the function hierarchy to the equipment structure will be thoroughly explained in the following chapters.

12 Function Hierarchy

Modularity is as described earlier as a tool to make complexity manageable, see chapter 3 Modularity. This can be done by creating a product architecture or function structure. The functional elements are described in a schematic/hierarchy matter where you find the overall function at the top and specific technologies or components at the lowest level. The physical elements are the parts/components and subassemblies that in its whole create the product, these parts are important when the modular architecture is defined. The modular architecture describes the parts/components and their functions and it clarifies the interactions between the parts (Ulrich and Eppinger, 2008).

The function hierarchy structures the intended capabilities/operations the vessel should perform. For example for an OSV typical capabilities are support operations, anchor handling etc. Each operation is built up by a set of smaller operations again, these operations are defined are functions and create the basis of determining which function modules that are necessary. For anchor handling the functional elements are e.g. deployment of anchor or retrieval of anchor.

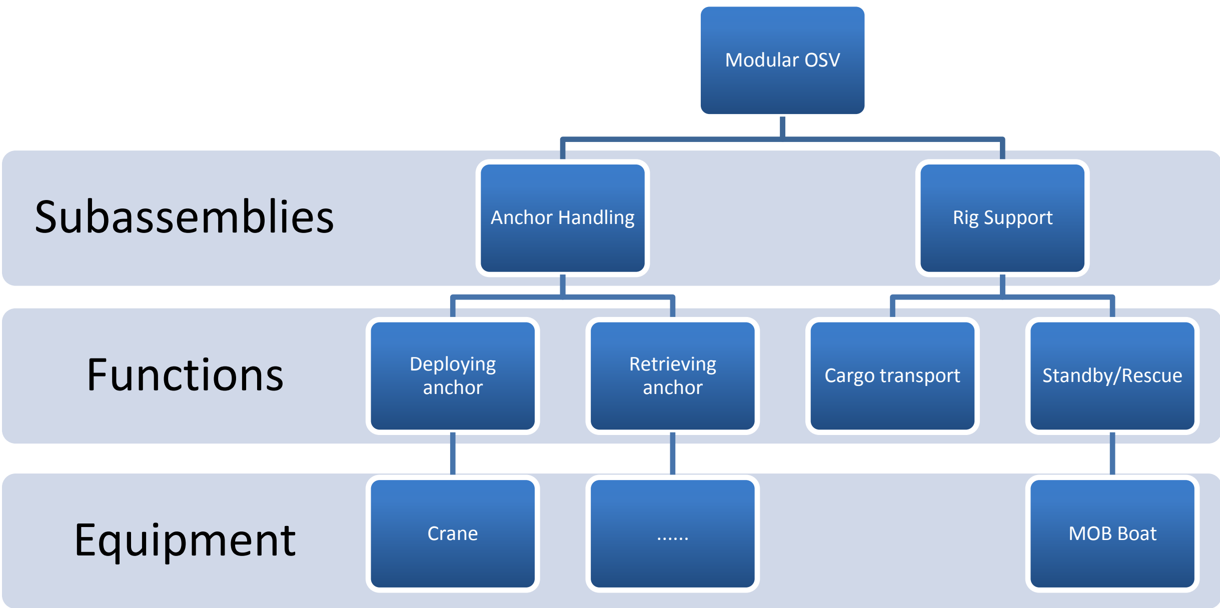

Figure 12-1 Part of function hierarchy tree of an OSV

Figure 12-1 shows how the layout of the product architecture/function hierarchy of an OSV. It is of course only a small part of the entire function hierarchy and is only meant for illustrative purposes.

After determining all the functions of the vessel, it is natural to determine the equipment modules that are needed to perform each function. The classification into equipment modules is a very important process. The equipment modules that are identified here create the basis for the further design process of the equipment structure.

There is a distinct connection between an accurate defined product architecture and high level of modularity. Due to the structured breakdown of the product into specific functions it is possible to divide these functions further into chunks or function modules. A well designed product architecture can not only be the difference between a well-designed product and a product that never sees the light of day, but it also helps the management of product change and upgrades, product variety and component standardization (Hölttä-Otto, 2005).

13 Design Structure Matrix

There can be found several theories on how a design structure matrix (DSM) typically is used. It is most often used to organize product development tasks or teams to minimize unnecessary design iterations in order to increase the efficiency of the design process. A DSM can also be useful as a part of the product architecture. A DSM consisting of parts or components can be defined as an architectural DSM, where the components or functions are placed on the row and columns of the matrix and interactions between them are mapped (Hölttä-Otto, 2005). How these interactions are represented in the matrix may vary from designer to designer. Typical representations may be strength of interaction i.e. dependencies or type of interaction i.e. direct or indirect. Figure 13-1 is an example of a typical layout of an architectural DSM.

	Function 1	Function 2	Function 3
Function 1	x		1
Function 2	1	x	1
Function 3			x

Figure 13-1 Typical layout for an design structure matrix

From the DSM we can obtain all dependencies in the product. The mark "1" identifies dependencies between the functions. From the DSM in Figure 13-1 we see that function 2 depends on function 1 and that functions 1 and 2 depends on function 3. It is not necessary that function 3 depends on function 1 or 2, or that function 1 depends on function 2.

So that the DSM is to be as most suitable and useful in the design of OSV's, I have implemented a few changes on the layout. It has not been my intention to reproduce the DSM as it is defined today, but create a platform suitable as support in the design process of the equipment structure for OSV's.

It is important to map both the interactions between functions and the modules and at the same time map the interactions between the functions themselves. There has been a need for a clear structure for the interactions between the vessel operations, the functions needed for the operations and the equipment modules that run the functions. The DSM provides the user with following information on the vessel:

- A clear structure defining the equipment modules that are needed to operate the functions.
- Some equipment modules cannot be installed or operated at the same time, due to e.g. space limitations or stability etc. These limitations are mapped in the matrix.

The matrix is a combination of two different DSM's. On one side you have the matrix which defines interactions between function modules and the different equipment. The other matrix describes interactions between the equipment modules. Figure 13-2 shows the two matrixes that in total create the final DSM for our design.

	Function 1	Function 2	Function 3
Equipment 1	1	1	
Equipment 2			2
Equipment 3		3	
Equipment 4	x		

Equipment 1	1	1		
Equipment 2			2	
Equipment 3		3		
Equipment 4	x			
	Equipment 1	Equipment 2	Equipment 3	Equipment 4

Figure 13-2 Design structure matrix adopted to suit the model

Figure 13-3 is an example of how the finalized DSM is structured.

	Function 1	Function 2	Function 3	
Equipment 1	1	1		
Equipment 2			2	
Equipment 3		3		
Equipment 4	x			
	Equipment 1	Equipment 2	Equipment 3	Equipment 4

Figure 13-3 Final DSM structure for mapping of equipment modules vs. functions

In this matrix we see that equipment 1 is needed to run functions 1 and 2. We also notice that equipment 1 and 4 are conflicting modules and are therefore marked with an "x", these modules cannot be used at the same time. Reasons for modules becoming conflicting can be that they occupy the same location or stability requirements are not fulfilled if the modules are installed and operate simultaneous. Further on we see that equipment 2 is needed for function 3 and that equipment 3 is needed for function 2.

A breakdown of this kind is very important and useful in the process of characterizing functions and modules when designing for modular capabilities.

14 Modular Complexity and Vessel Influence

After the establishment of the function hierarchy and the DSM it is possible to evaluate the modular complexity of the design. This is done from two points of views;

- The modules by itself. Modular readiness, installation requirements etc.
- The modules influence on the vessel. Footprint area, stability etc.

The possibility of modular capabilities on a vessel is very much determined by the function modules. Are the function modules adaptable for modular capabilities will be essential to determine when evaluating the feasibility of modular capabilities. The modules influence on the vessel is important to establish because the vessel must be built for the worst case scenario regarding stability, size etc. and therefore modules with high influence on the vessel might not be so beneficial to use due to the added cost of increasing the main dimensions.

14.1 Review of Equipment Modularity Potential

Each equipment module is evaluated in the following 3 categories:

1. Technology Readiness Level (TRL).
2. Degree of Installation Complexity
3. Modular Space Potential

The Technology Readiness Levels gives an indication on to which extent each module are capable of modular application i.e. is the system interface ready or is the module complexity possible to handle with regards to replacements etc. If the equipment are considered modular today the technology readiness will be high, if the module technology are far from having modular capabilities the TRL would be low. The score each module is given has in this field been reversed so that a high TRL will give a score of 1 and low TRL a score of 3. This is done so that all grades represent the same value. A low number indicates "positive values" and high grades indicate a "negative" score.

An important factor to consider is the degree of installation complexity. Degree of installation complexity gives an overview on the level of difficulty installing each equipment module. For instance large modules are difficult to handle and requires significant foundation and therefore the installation becomes complex. Small modules that require little or none external support i.e. crane, welding etc. have a small level of installation complexity. This is an important factor that must be considered when recommending a timeframe for replacement. Smaller modules with low installation complexity can have a lower timeframe between replacements due to shorter re-construction time.

The evaluation of the modular space potential category has its starting point from the type 3 modularity, see chapter 3.2 Modular Typology. The question that must be considered is: Can modules that are not at the time in use be used for other capabilities and if so, which modules and to which use. For example can we in short amount of time re-construct the moonpool or the ROV hangar in order to use them as storage room for equipment, tools etc.

The categories are also given different weighting after the importance of them. For example is the installation complexity of a module more important than the modular space potential when determining the potential of modular are therefore also weighted higher.

			Weighting:	1,5	2	1	
Equipment Modules	TRL	Installation complexity	Modular space potential	TRL	Installation complexity	Modular space	**Sum**
Module 1	High	Medium	Low	1	2	1	**6,5**

Table 14-1 Lay out of modular complexity evaluation

Table 14-1 shows how each module can be evaluated and weighted. The result of the evaluation gives an indication on how well each module are suited for modular application and will play an greater role later when evaluating and concluding with an modular approach for each module.

For better understanding of the total results it is useful dividing the range of results into intervals. Where the upper bounds define modules with difficult modular application and lower bounds determine modules that are highly applicable for modular application. The boundaries can be found by the following model:

Boundary limits:

$$B_L = (R_T - R_{\min})(x_w) \tag{6}$$

$$U_B = R_T - B_L \tag{7}$$

$$L_B = R_{\min} + B_L \tag{8}$$

And if

$$R_m \geq U_B = Complex \tag{9}$$

$$R_m \leq L_B = Modular \tag{10}$$

$$L_B \leq R_m \leq U_B = Normal \tag{11}$$

Where:

B_L	Interval for upper and lower boundary,
R_T	Total possible rating for modules
$\mathrm{R}_{\min}$	Lowest possible rating for modules
x_w	Fraction of upper and lower boundary interval
U_B	Upper boundary for complex module
L_B	Lower boundary for simple module
R_m	Rating for specific module m

The fraction of upper and lower boundary can be set to standard interval e.g. 20 %, meaning that the upper and lower 20 % of the total possible score determines the boundaries for the modules. Figure 14-1 illustrates these boundaries on a set of modules. The graph line indicates the density of modules at the given result seen on the horizontal axis. The vertical lines define the upper and lower boundaries for this scenario.

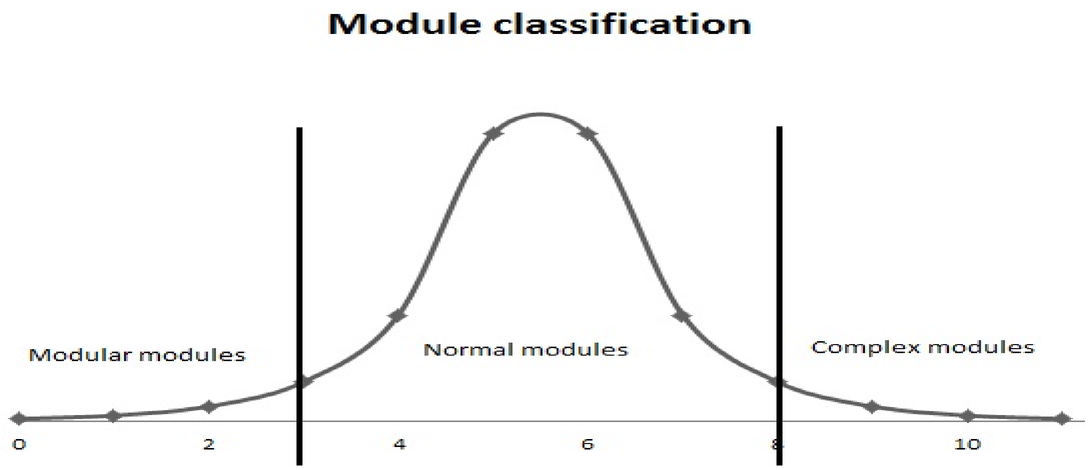

Figure 14-1 Module classification with three intervals

It is possible to extend this model even further so that modules that are too complex for modular approach are determined already by this model. Earlier we divided the boundaries into 3 categories, but if we introduce two new boundaries with even higher percentile interval we can determine if a module is to complex. Figure 14-2 illustrates the implementation of more strict boundaries and shows how modules scoring above a predetermined score are defined too complex and therefore not suited for modular approach. This will also require a more detailed evaluation of each module and the rating system should also be expanded if expanding the boundary levels.

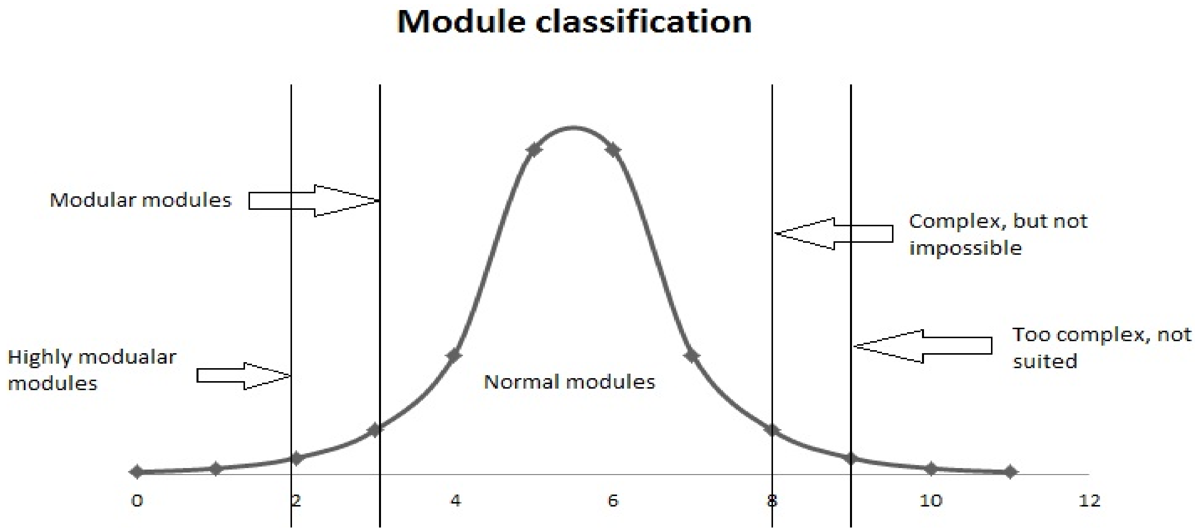

Figure 14-2 Extended module classification with 5 intervals

14.2 Review of Modular Influence on the Vessel

Applying modular capabilities influences many design parameters on the vessel. Mapping the modules and their effects on the design and the vessel are important parts of the design of modular vessels. This especially since the implementation of modular capabilities should to some degree be based on a cost/benefit comparison of the capabilities and single modules that have high effects on the vessels dimensioning are therefore often tilting heavier towards the costs side in the comparison.

Each equipment module should therefore be carefully reviewed and graded in their effects on the following three categories.

1. Vessels main dimensions
2. Stability
3. Footprint loss

Large and complicated modules have great impact on the vessels main dimensions and stability. If these impacts become to big there is a very large impact on the building costs and operating costs of the vessel. It is therefore important that these modules and the use of them are thoroughly considered with basis in the increasing cost vs. the benefit of the module capability.

Footprint area is important for OSV's and especially on cargo deck/work deck. It is therefore important to evaluate the effects each equipment module will have on the vessels footprint area. It can be very expensive installing a module that occupies much of the vessels cargo deck footprint area and especially if the module is seldom in use.

These three categories are meant to cover the main aspects of how any equipment module can affect the vessel in a costly matter. Depending on what is considered more or less important each category can again be given different weighting e.g. it is desirable with high stability and not to over dimensioned vessel and these are therefore weighted with 1,5 each whilst footprint area are weighted 1.

Table 14-2 is a proposed lay out for the design evaluation with weighting and grading of each module and category.

			Weighting:	1	1,5	1,5	
Equipment Modules:	Footprint loss	Vessel dimensioning	Stability	Footprint	Dimensioning	Stability	**Sum**
Module 1	Low	Medium	Low	1	2	1	**5**

Table 14-2 Lay out of vessel influence evaluation

As for the modular complexity also the sum of the categories for the vessel influence are an indication on how the modules are suited for modular application. High rating gives an indication of a difficult modular application for the module.

The same model as used on modular complexity previously can and should be implemented on vessel influence to establish boundaries for maximum allowable degree of vessel influence.

15 SUMMARIZING INPUT

Having established both the complexity of the modules itself and their influence on the vessel specifics it is possible to make more qualified assumptions on which modules that are suited for modular application and how often the modules should be exchanged.

Some equipment modules can be used in several operations modes. For these modules it might be more cost efficient to implement them in part of the standard outfitting. This can avoid a high number of unnecessary re-conversion of the vessel. The level of multifunction is found from the DSM described earlier. A module that repeats in several functions has a higher degree of multifunction.

There are also other factors which can affect the conversion intervals. This is the time required to install the module on the vessel and what external support the installation requires.

Equipment Modules:	Modular complexity	Vessel influence	Installation Time	External Support	Multifunction
Module 1	Normal	Modular	Low	None	Low
Module 2	Complex	Complex	High	External	Medium

Table 15-1 Overview of finalized equipment data

Table 15-1 gives an overview of the structure of the equipment modules and their respective results.

16 FINAL STRUCTURE

As all necessary information is established in the input summary the designer can structure the equipment on the vessel. This involves defining modules that are most suited as part of the standard outfitting, modules that will not be exchanged, and which modules that can be exchanged for other operations. Another important factor taken into consideration is which modules are absolutely necessary for the operations and which are optional; this information is provided from the DSM.

Since many of the operations require some interactions between several different modules, it's therefore important to relate the modules back to the operations and structure the equipment with respect to each operation and not only each module for itself.

If modules and their respective operations are too complex for being beneficial as a modular capability there are two different solutions. The modules can either be installed as a part of the standard outfitting or exclude the whole operation from the vessels capabilities. Table 16-1 shows the proposed structure for how the final structure of the vessels can be displayed. Operations and modules that for different reasons have been excluded from the vessel during the screening process are not included in the table.

The proposed exchange interval sets a limit for the minimum time a module is to be used on the vessel, modules are given long intervals if they for example are difficult to handle, complex installation and/or long installation time. Typical exchange requirements can be e.g. contract, operation or none. If modules are to be exchanges between contracts it is on a long term perspective, this can be between shorter periods to over several years depending on the duration of the contract. An operation based exchange allows for modules to be exchanged several times in one contract period, this gives the contract owners higher flexibility and possible lower standby time for the vessel between operations. If there are none requirements the module can be exchanged at any given time, this is suited for modules that are small, simple and easy to install quickly without special external support.

	Standard or modular outfitting	Optional	Proposed exchange interval
Operation 1			**Contract**
Module 1	Modular	Required	Operation
Module 2	Modular	Optional	Any
Operation 2			**Operation**
Module 3	Standard	Required	Any
Operation 3			**Contract**
Module 2	Modular	Required	Contract

Table 16-1 Final equipment structure lay out

17 CASE STUDY

The following chapters give a step-by-step process of how the methodology can be implemented on an outline specification given from ship owner. The intention with the case study is to give a more practical introduction to the methodology as well as to some degree evaluate the feasibility of a modular capability concept on offshore support vessels.

17.1 OUTLINE SPECIFICATION SUMMARY

A fictive outline specification is the foundation for the case study. It will not be repeated in its whole here, but a short summary will be given. The whole outline specification can be found in Appendix III – Outline Specification.

The vessel is intended to perform a set of given operations at different periods and must be designed thereafter. Equipment modules are to be swapped with other equipment modules and it is therefore important that the vessel is adequate designed to operate all intended functions. It is desirable that the vessel has high endurance and it must be able to achieve relatively high cruising speed. This is to reduce time in transit for module exchange operations, increase the possibility of operating at both the North Sea and the Brazilian continental shelf as well as having high preparedness to emergency operations.

The vessel will operate as a construction vessel for the first operation period. The prospects for the vessel after the period as construction vessel is finished is uncertain, but will be one of the following; Anchor handling and towing, pipe lay operations or rig support.

17.2 OPERATION OVERVIEW

For better understanding of the different capabilities the vessel will perform follows a short summary of the different operations.

17.2.1 CONSTRUCTION OPERATIONS (RITCHIE, 2008)

Vessels that perform construction operations can be recognized by their size and being highly specialized. Construction operations are generally to lift and deploy subsea installation equipment on the seabed. For some construction operations it is also a need for dive support from either professional divers or from remotely operated vehicles (ROV's). For safe lifting and lowering of equipment are often construction vessels built with moonpool. The equipment handling tower or construction tower is the most important equipment for construction operations.

17.2.2 Anchor Handling and Towing (White, 2004)

For anchor handling operations the vessels must be fitted with large deck space in the aft, high winch capacity, storage bins for rig chains and also auxiliary cargo handling equipment such as cranes. Anchor handling operations also affects the design of the vessel. It is important for the vessel to have good stability especially when operating with heavy moorings and anchors at the aft. The pulling power and required wire/rope capacity is one of the major design parameters. The hull must withstand the winch loads and brake forces and the cargo space must be sufficient. The cargo space requirement for these operations is only increasing as drilling operations moves to deeper waters.

17.2.3 Pipe Lay (Global Security Pipelay, 2011)

Vessels that perform pipe lay operations are very specialized and they require extensive systems and equipment. Their main operation is installation of flow lines and umbilical's for transportation of oil and gas from production facilities off shore to shore. Important equipment are pipe reels for storage, ramp for the deployment of the pipes, large cranes etc. The added weight of the pipes and equipment has great impact on the stability of the vessel and must be carefully considered.

17.2.4 Support Operations (White, 2004)

Support vessels are mainly performing supply operations for offshore rigs and production platforms. Offshore rigs and production platforms require periodic re-supply of amongst other: fuel, fresh water, food, equipment and a number of fluids required for drilling operations. The vessels are also fitted with tanks for drilling mud, pulverized cement and for specific chemicals needed for drilling operations. In some cases there is also need to transport chemicals from the production area to shore for more proper disposal or recycling. Platform supply vessels can also be used for transportation of personnel and standby rescue operations like firefighting, oil recovery and rescue operations (Global Security AHTS, 2011).

18 Function Hierarchy

The establishment of the function hierarchy is based on the different operations that the vessel is intended to perform.

18.1 Operational Functions

Operational functions are divided into two categories, primary operations and secondary operations. Primary operations are defined as the operations that the vessel is capable to carry out without any further re-construction. Secondary operations are those operations the vessel are designed for and are able to carry out after smaller and/or more extent re-construction. Both categories are intended as long-term outfitting (longer contracts, up to several years), but smaller equipment modules and functions should and will be exchanged on shorter prospects (depending on availability, but can be down to months). The time interval for exchanging a module must be defined and considered from a cost/benefit point of view. Following is a description of the different operations and the functions required in each operation.

Primary operations:

The vessel is to operate as a construction and support vessel (CSV). It shall have capabilities to provide the following multi-function support facilities.

- Sub-sea Construction
- Top side Construction
- ROV support for sub-sea construction
- Transport fresh water, diesel oil and deck cargoes, support operations

Secondary operations:

The vessel should after re-construction be able to carry out the functions which are listed below.

Anchor Handling and Towing

- Anchor handling support for rigs, deployment and retrieval.
- Handling of equipment on deck.
- Transport fresh water, diesel oil, deck cargoes, bulk cargoes liquid mud, materials & equipment.
- Personnel transportation.
- Tow/Move of Rigs.

Pipe Lay

- Installation of sub-sea pipes.
- Storage for pipe reels on or below deck.

Support

- Cargo/Equipment transportation
- Liquid and dry bulk storage/transportation
- Personnel transportation
- Standby(Fire and oil spill)/Rescue

Based on these functions we can now determine the specific equipment that is needed for each function and operation.

18.2 Equipment Modules

The full list of required equipment modules can be found in Appendix IV – Equipment Modules. The equipment modules are divided in to two categories, A and B modules. This is done to identify and separate modules that are absolutely required for performing the functions required (A modules) and the modules that are not necessary (B modules), but still are desirable for the ship owner to have on the vessel when performing the operation. An example of this is moonpool which is an A module if the vessel is operating as a construction vessel, but if conducting ROV operations moonpool is not absolute necessary and are therefore defined as a B module. The required equipment modules are found from an analysis of each function and what equipment that is needed to perform each function.

The list of equipment is not necessary a complete list of all required modules for the different operations. It is not in the intention of this master thesis to necessary identifying all modules, but to identify and structure equipment modules for modular capabilities and for this the modules that are chosen is sufficient.

Some of the modules already have a specific design where only the interface between the hull and the module can be changed; other modules are less constrained to one design and are more flexible such as extended accommodation, storage tanks for liquid or dry bulk etc. This case study assumes one way of designing these modules which can be found in Appendix V – Equipment Description and it is important to have an understanding of how these modules are designed when continuing the process of this case study.

Having determined all functions and their equipment these can now be structured and illustrated in a function hierarchy. Figure 18-1 is part of the total function hierarchy and shows the different operations and the functions at the lowest level. Due to space limitations not all functions has been included in the figure, but the first functions is included for illustrative purposes. All functions can be found in the DSM. The equipment modules needed for each function are not a part of the figure. The list of required and desired equipment is found in Appendix IV – Equipment Modules.

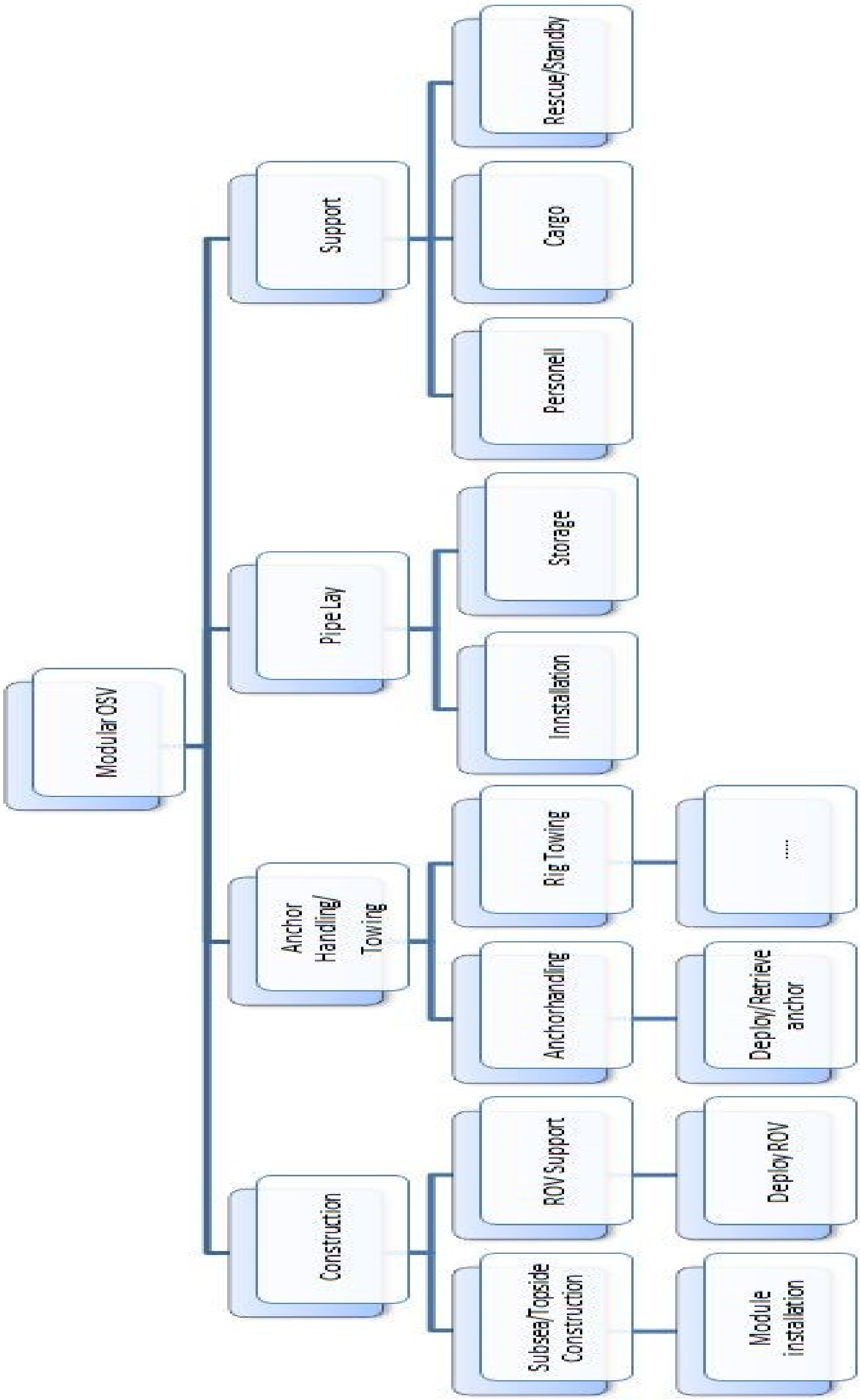

Figure 18-1 Function hierarchy of case modular OSV

19 Equipment Modules

19.1 Equipment Interaction

It is now possible to establish the design structure matrix for the equipment modules and functions.

For illustrative purposes only a part of the DSM are included in the report, the whole DSM can be found in Appendix VI – Design Structure Matrix. Figure 19-1 shows the first part of the DSM including the operational functions for construction operations and the required equipment modules for these functions.

Operations:	Construction					
Modules:	Subsea Installation	Topside installation	Equipment handling	Accomodate extra personell	Equipment storage	ROV Support
Heave Compensated Knucleboom	1	1	1			
Equipment Handling Tower/Construction Tower	1					
Moonpool	1					[1]
Cargo Deck Area	1	1	1		1	
Auxiallary Cranes e.g. Rail Cranes			1		1	
ROV Hangar						1
ROV Launch and Recovery						1
Extended Accomodation				1		

Figure 19-1 Small part of the DSM for the case

The DSM shows that large deck area and heave compensated main crane is essential equipment modules for construction operations. Large deck area is in fact not an equipment module, but is considered a part of the equipment structure since it is required in many of the operational phases and the vessel must be capable of having additional deck area for cargo.

If a module is indicated with [1] it illustrates that the module are optional modules for the operation and that they are not critical for full function performance. For example we see that a moonpool is not critical for ROV operations, ROV's can be launched from the side of the vessel and is therefore an optional module. Even though moonpool is optional for ROV operations, the module is critical in order to perform subsea installation and must therefore be installed.

In the complete DSM equipment modules are connected to the operations with numbers. 1 is used on equipment modules required for construction operations, 2 for anchor handling, 3 for towing, 4 for pipe lay and 5 for support operations. Some equipment modules may be marked with an x; this indicates that it is not possible to operate with these modules at the same time.

Some modules such as the heave compensated crane, auxiliary cranes and also a large deck area are equipment that is useful in more than 2 operational profiles. The other modules are more mission specific and are mainly only used for one operation, with of course exceptions where the equipment modules also can be beneficial on other operations e.g. ROV functions and moonpool.

20 EQUIPMENT EVALUATION

The modules are evaluated in the two different categories modular complexity and vessel influence. These two categories found the basis for determining intervals for module exchange between operations and in correlation with the DSM establish equipment structure on the vessel with regards to standard outfitting and modular outfitting.

20.1 MODULAR COMPLEXITY

Modular complexity evaluates each equipment module with regards to the feasibility for modular application on the vessel.

Table 20-1 shows the numerical values of the equipment modules in each category and the total score for all modules. The background for each grade has not been included here, but can be read in its whole in Appendix VII – Modular Complexity Description. The three categories have also been given different weighing since some of them are significantly more important than others. The installation complexity and the level of modular technology readiness are considered more important and are weighted respectively 2 and 1,5.

The maximum total rating for each equipment are with this weighting is 13,5 and the minimum rating is 4,5. The model for calculating the modules boundary levels as described in chapter 14.1 Review of Equipment Modularity Potential has been used and the results can be found in the Table 20-1. For modular complexity the upper and lower boundaries were set to 30 % giving a lower bound at 7,2 and upper at 10,8. Since the modules only has been rated from low to high (1 – 3) with regard to modular complexity and vessel influence, there has only been set one upper and lower boundaries. For higher boundaries a more extent evaluation of each module is required.

Weighting:	**1,5**	**2**	**1**		
Equipment modules	Modularity	Installation	Space potential	Sum	**Result**
Heave compensated knuckle boom	2	2,5	1	9	**Normal**
Equipment handling tower	2,5	3	1	10,75	**Normal**
Moonpool	3	3	2	12,5	**Complex**
Large deck area for equipment storage	2	3	1	10	**Normal**
Auxiliary Cranes: Rail cranes	1	1,5	1	5,5	**Modular**
ROV Hangar	1,5	2	2	8,25	**Normal**
ROV Launch and Recovery	1	2	1	6,5	**Modular**
Extended accommodation	1	2	1	7,5	**Modular**
Anchor winch	3	3	1	11,5	**Complex**
Sternroller	2	2	1	8	**Normal**
Sharkjaw	1	1	1	4,5	**Modular**
Storage room for chains & ropes	2	3	2	11	**Complex**
Towing pins	1	1	1	4,5	**Modular**
Ramp fleeting and elevation system	2,5	2,5	1	9,75	**Normal**
Pipe storage for deck (Deck reel)	1	1,5	1	5,5	**Modular**
Storage tanks for dry & liquid bulk	2	1,5	2	8	**Normal**
External Firefighting system	3	3	1	11,5	**Complex**
Oil recovery equipment	1,5	1,5	1	6,25	**Modular**

Table 20-1 Modular complexity evaluation

The evaluation of modular complexity indicates that equipment such as auxiliary cranes, shark jaws and towing pins are ideal equipment for a modular approach and should not require complex reconstruction to swap modules. Equipment such as moonpool, anchor winch and other modules with high score are not ideal for a modular approach. These modules will require massive and/or complex re construction to swap and should therefore be given higher limits when assigning exchange intervals for the modules.

The challenge with specialized and complex system modules are evident form this table. There are few modules that have any modular space potential except ROV Hangar, storage tanks and storage room for chains and ropes. We also see that the trend for almost all modules is a high degree of installation complexity; the average lies from medium (2) to high (3). This gives us reason to believe that there are few modules that quickly and easily can be exchanged and that each conversion between operation profiles will most likely require more extensive re construction.

20.2 Module Influence on the Vessel

Each module has different influence both in terms of size and cost on the vessel. If modules create a very negative effect on the vessel or its life cycle cost it must be thoroughly considered whether the module and its belonging function is beneficial for the vessel. Can the income that comes from the function outshine the negative effects on the vessel and ship owner caused by it?

Again each equipment module is rated on different categories and given a total score. The total score is based on the score given in each category, but some categories are given a higher weighting on the total score. In this evaluation the effects on stability and dimensioning are considered equally important compared to footprint area and are therefore weighted with 1,5.

The maximum and worst rating possible in this scenario is 12 while the best is 4. Using the same model as earlier upper and lower bound has been calculated to respectively 9,6 and 6,4. Table 20-2 summarizes the result or the vessel influence evaluation.

Weighting	**1**	**1,5**	**1,5**		
Equipment modules	Footprint	Dimensioning	Stability	SUM	**Result:**
Heave compensated knuckle boom	1	2,5	3	9,25	**Normal**
Equipment handling tower	3	3	3	12	**Complex**
Moonpool	3	3	3	12	**Complex**
Large deck area for equipment storage	3	3	1	9	**Normal**
Auxiliary Cranes: Rail cranes	1	2	2	7	**Normal**
ROV Hangar	2	2	2	8	**Normal**
ROV Launch and Recovery	2	2	2	8	**Normal**
Extended accommodation	2,5	2,5	1,5	8,5	**Normal**
Anchor winch	3	3	2,5	11,25	**Complex**
Sternroller	1	1,5	1	4,75	**Modular**
Sharkjaw	1	1,5	1	4,75	**Modular**
Storage room for chains & ropes	2	2	2	8	**Normal**
Towing pins	1	2	1	5,5	**Modular**
Ramp fleeting and elevation system	2	3	3	11	**Complex**
Pipe storage for deck (Deck reel)	2,5	2	3	10	**Complex**
Storage tanks for dry & liquid bulk	3	2	2	9	**Normal**
External Firefighting system	2	1,5	1	5,75	**Modular**
Oil recovery equipment	3	2	1,5	8,25	**Normal**

Table 20-2 Vessel influence evaluation

The modules with low total rating have a limited effect on the vessel with regards to stability requirements, dimensioning and footprint.

The same trend follows for this evaluation as for the modular complexity evaluation. The biggest modules in size and weight are the modules that receive the highest scores and are those that are least suited for modular use. These modules are, amongst others, anchor winch, ramp fleeting and elevation system, heave compensated crane etc. We also see that the small modules such as towing pins, shark jaw, stern roller etc. are very suited for a modular approach. The low scores are a result of small modules with low weight and are centered on the vessel resulting in little effect on the vessels stability.

21 SUMMARIZING INPUT

The equipment modules on the vessel have now been evaluated in ways of modularity and level of influence on the vessel. This information and also the predicted time to exchange a module and what support is needed for the exchange are summarized in Table 21-1. The support needed for installing the modules are divided into two categories, external support and vessel crane. External support is if the vessel needs support from cranes and equipment from a yard and vessel crane is the vessel can install the module only by support from the vessel crane, implicit that a suited crane already is installed on the vessel.

Equipment Modules:	Modular complexity	Vessel influence	Time consumption	Support	Multi function
Heave compensated knuckle boom	Normal	Normal	Medium to High	External	High
Construction Tower	Normal	Complex	High	External	Low
Moonpool	Complex	Complex	High	External	Medium
Large deck area for equipment storage	Normal	Normal	Dependent on other modules	Dependen t on other modules	High
Auxiliary Cranes: Rail cranes	Modular	Normal	Low	Vessel crane	Medium to High
ROV Hangar	Normal	Normal	Medium	Vessel Crane	Medium
ROV Launch and Recovery	Modular	Normal	Low	Vessel crane	Medium
Extended accommodation	Modular	Normal	Low	External	Low to Medium
Anchor winch	Complex	Complex	High	External	Low
Sternroller	Normal	Modular	Low	Vessel crane	Low
Sharkjaw	Modular	Modular	Low	Vessel crane	Low
Storage room for chains & ropes	Complex	Normal	Medium to High	External	Medium
Towing pins	Modular	Modular	Low	Vessel crane	Low
Ramp fleeting and elevation system	Normal	Complex	Medium to High	External	Low
Pipe storage for deck (Deck reel)	Modular	Complex	Low	Vessel crane	Low
Storage tanks for dry & liquid bulk	Normal	Normal	Medium	Above deck = Crane Below deck = External	Low
External Firefighting system	Complex	Modular	Medium	External	Low
Oil recovery equipment	Modular	Normal	Medium	Medium	Low

Table 21-1 Overview of final equipment data

An important decision factor for the equipment structure is of course the modules degree of multifunction. Data from the DSM is used as basis to find the degree of multifunction.

Again we see that large modules with high score on modular complexity and vessel influence often have higher time consumption for installation and also a higher need for external support than smaller less complex modules.

22 EQUIPMENT STRUCTURE

The equipment modules have been summarized and it is now possible to develop the final structure of the equipment on the vessel and the different operations.

The final equipment structure are divided into two different categories; standard and modular outfitting.

22.1 STANDARD OUTFITTING

Standard outfitting are those modules that are designed to be on the vessel through all operations. This is modules that either is too complex for modularity or those which are used in so many operations so it is more cost beneficial to keep the modules on the vessel at all times. There are very high requirements for a module to be part of the standard outfitting in order to maintain a high degree of modular flexibility and not having a multi-purpose vessel.

The knuckle boom is perhaps the most obvious module that is among the standard outfitting, its values is within normal on vessel influence and modular complexity, as well as long installation time, need for external support and mostly it has a very high degree of multi-function. The crane is not required, but at least desired in all the main operations.

The moonpool is one of the most complex modules; it has high influence on the vessel and is very complex with regards to modular application. The complexity of the module and the high installation time makes the moonpool more beneficial as part of the standard outfitting. When the moonpool is not needed it might be possible to install a new module filling the space of the moonpool and possible acting as cargo room and deck area. For instance can the moonpool act as storage room for dry or liquid bulk when performing supply duties. This can be done by installing a container module with tanks that fit the moonpool and can be locked in a position surrounding the moonpool.

Even though sufficient cargo deck is not a module in itself it must be taken height for having sufficient cargo deck in all operations when designing the vessel and are therefore part of the standard outfitting.

Firefighting systems are becoming more and more common on OSV's and from our calculations the module is considered too be complex with regards to modularity and modular with regards to vessel influence. This taken into consideration the firefighting systems is more applicable as part of the standard outfitting. This is because of the complexity of piping and pumps which is difficult to operate as modular and must therefore either be on the vessel at all time or never.

The last module taken into the standard outfitting is the storage room for chains and ropes. The storage room is located below the anchor winch under the main deck. The location makes the module very difficult to install and remove. Because of the complexity of the module and that the module has limited influence on the vessel it is advised that also this module is considered as part of the standard outfitting.

22.2 Modular Equipment

The remaining modules are those that form the modular capabilities for the vessel. The modules have now been related back to the respective operations to get a more clear view of each operation and its equipment.

The proposed interval for exchange is divided into three different categories:

1. Contract – Long term. Large and complicated modules which require extensive conversion are advised to be swapped between large contracts with a longer perspective.
2. Operations. Modules that are simpler to install and that requires less support can be exchanged more often and an exchange can therefore be done between operations within one contract.
3. Any. For those modules with minimal installation time and limited need for external support can be exchanged at any point and are therefore not provided with a specific interval.

Table 22-1 shows the structure of the modular equipment needed for construction operations. It also indicates whether the equipment modules are optional or required for the operation and also the modules exchange interval. Required operations are operation specific modules which cannot operate unless connecting modules are installed. Optional modules are highly flexible and are not connected with other modules in order to perform operations. These modules can in theory be used with all equipment structure unless it is prohibited for reasons as location conflict, stability issues etc. Conflicting modules are determined from the DSM.

The modules that are part of the standard outfitting are not included in the following tables.

Construction	Standard or modular equipment	Optional	Proposed exchange interval
Construction Tower	Modular	Required	Contract - Long term
Auxiliary Cranes e.g. Rail Cranes	Modular	Required	Any
ROV Hangar	Modular	Optional	Operation
ROV Launch and Recovery	Modular	Optional	Operation
Extended Accommodation	Modular	Optional	Operation

Table 22-1 Equipment structure for construction operations

The ROV modules are optional for construction operations and can be installed on the vessel when needed. The construction tower is essential for the construction operation and because of the complex installation and the high vessel influence it is proposed an exchange interval that is contract – long term.

In anchor handling and towing operations it is only the anchor winch that has a high exchange interval. The rest of the modules needed for these operations are given the lowest exchange interval. This is because the modules are small, low requirements for installation support and they have limited influence on the vessel. Table 22-2 shows the modular equipment structure for anchor handling and towing operations.

Anchor Handling	**Standard or modular equipment**	**Optional**	**Proposed exchange interval**
Auxiliary Cranes e.g. Rail Cranes	Modular	Required	Any
Anchor winch	Modular	Required	Contract - Long term
Sternroller	Modular	Required	Any
Shark Jaw	Modular	Required	Any
Towing			
Anchor winch	Modular	Required	Contract - Long term
Towing pins	Modular	Required	Any

Table 22-2 Equipment structure for anchor handling and towing operations

The modules for pipe laying operations are large and complex and since they rely equally on each other they are both given long exchange intervals. Table 22-3 shows equipment structure for pipe lay operations.

Pipe lay	**Standard or modular equipment**	**Optional**	**Proposed exchange interval**
Ramp fleeting and elevation system	Modular	Required	Contract - Long term
Pipe storage (Deck reel)	Modular	Required	Contract - Long term

Table 22-3 Equipment structure for pipe lay operations

The final operation is support. Support operations are wide and have many different capabilities, making it the operation that is most applicable for modular capabilities. The modules that are needed for support capabilities are in a much higher degree independent compared to modules in the other operations. This is evident from the high amount of optional modules for the operation and the general low exchange interval for the modules. Table 22-4 summarizes the equipment structure for support operations.

Support	**Standard or modular equipment**	**Optional**	**Proposed exchange interval**
Auxiliary Cranes e.g. Rail Cranes	Modular	Required	Any
ROV Hangar	Modular	Optional	Operation
ROV Launch and Recovery	Modular	Optional	Operation
Extended Accommodation	Modular	Optional	Operation
Storage tanks for cargo	Modular	Required	Contract - Long term
Oil recovery equipment	Modular	Optional	Any

Table 22-4 Equipment structure for support operations

Extended accommodation, ROV capabilities and oil recovery are equipment modules that are highly suited as modular capabilities and since they are optional modules they can also be used for the other operations if desirable and possible with regards to the DSM.

The vessel can with this equipment structure offer 4 different operations (anchor handling and towing operations are merged because of similar modules). The vessel can convert to one of the remaining operations between contracts, or if operating on the spot market it can convert if there is a clear uprising in demand and spot price for one operation and the economical predictions allow for a conversion.

Besides the major operation that require longer intervals the vessel can also supply minor operations with shorter conversion intervals such as ROV operations, minor supply operations, oil recovery, accommodation for extra personnel etc.

23 CONCLUDING REMARKS

Implementation of modular capabilities is in a continuously development, especially in the fields of naval military vessels. But the challenge which most of the concepts faces is to clearly separate modular design and construction with modular capabilities. Many of the concepts are utilizing modularity solely in the design and construction phase whilst modularity in the operations phase vanishes. The development of the concept must be directed more towards modularity in the operation phase to increase operational flexibility.

Modular capabilities on offshore support vessels has both several advantages and dis advantages. In the early stages of concept development it is also difficult to give definite conclusion, but the concept evaluation has given indication of where the advantages or most promising as well as indicating where challenges may be met. The most promising aspect is the increased operational flexibility which again leads to higher vessel utilization and a possible fleet reduction. Other positive outlooks are the vessels receptiveness for new equipment modules that follows from the standard interface and systems solutions used on the modules. This makes the vessels more competitive against future vessels with new technology.

As said there are also some aspects were the definite outcome is not yet determined. The outcome of the costs are very dependent of at which level the concept is implemented. The cost savings recognized with the concept will not take effect before a larger fleet of vessels are in operation. A model has been presented to calculate the cost of a possible conversion between operations has been presented, but the model is not validated with reliable values from the industry.

From an environmental perspective there are also aspects that can tilt many ways. A fleet reduction will lead to emissions reduction, but at the same time will the increased dimensions of the vessels and the increased transportation to and from conversions lead to an increase in emissions. The most reasonable approach is to focus less on modular capabilities contribution to the environment and rather continue the development of more environmental friendly propulsion systems, fuel etc. to increase sustainability.

Factors undermining modular capabilities are several, but most of all the high complexity of the equipment modules which makes it difficult to establish a standard interface and handling the equipment under a conversion.

Comparing the modular capability concept against traditional OSV's and multi-purpose vessels much of the same advantages found earlier. It also shows that one concept does not necessary mean the end of another. Operational flexibility comes with the cost of hull efficiency, mission specific efficiency and also at some degree building time and costs. The better concept will in the end be determined mainly of which of these attributes is considered most valuable by the ship owner.

The methodology developed to structure the equipment modules on vessels with modular capabilities has promising prospects in the future and can also be implemented on other vessel types. The DSM gives a great overview of the structure of the equipment and the module evaluation in regards to modular complexity and vessel influence increases and structures the knowledge of each module. The equipment module evaluation in correlation with the model for determining upper and lower boundaries of each module provides an accurate structure of the equipment's level of modular applicability.

The case study gives an example of the methodology in use and gives us valuable information on both the functionality of the methodology and also to some degree the feasibility of modular capabilities on OSV's. The case shows that the methodology is successful in ways of being a step by step model to provide an equipment structure of the modular capabilities. There is a natural transition between the steps in the model leading the designer toward the equipment structure and module exchange intervals. It is also evident from the case study that modular capabilities is difficult to deliver on short perspectives, the modules are complex and there are many dependencies between the modules and it is therefore a need for long exchange intervals between operations.

24 FURTHER PROSPECTS

There are several possible steps to develop the model and the modular capabilities concept further. This chapter is divided in two parts, steps that focus on concept development and those steps that are direct development and improvements of the model.

CONCEPT DEVELOPMENT

Modular capabilities on OSV's are a relatively new concept and the research on this field is therefore rather untouched. Continuing the research is therefore essential in order for the concept to grow and this can be done by continuing the concept evaluation that has been done in this MSc thesis and at the same time increasing the level of accuracy of the results.

With a starting point from the cost study done in this report and with collaboration from yards is it possible to produce a more accurate prediction of the vessel conversion between operations. As well as performing a more thorough cost study, it is valuable with a more precise estimate of the conversion time.

One of the most restraining factors for the concept is the equipment modules. The high degree of complexity combined with low level of modularity makes the concept difficult to implement. Increasing the emphasis on each module and improving and modularizing the design of the modules can contribute to an easier implantation of modular capabilities on the vessels. It is therefore advised to consider the modules separately and developing new design for the modules where standard interfaces and modularity is the driving factors for the design.

MODEL DEVELOPMENT

There are some clear aspects with the model that should be developed further. First of all is an improvement of the modular complexity chart and the vessel influence chart. This can be done in several ways, but the most obvious is a more accurate evaluation of each module and at the same time extending the scale from 1-3 to for example 1-10 for each model, giving more accurate and reliable results. With more accurate results for the modular complexity and vessel influence charts it is also possible to extend the model defining upper and lower boundaries. This model can be extended by introducing new secondary upper and lower boundaries resulting in further categories for each model. This will give even better understanding of the results.

A challenge with modular capability on OSV's is the equipment location. Many modules have predetermined location from the specific operation and many modules have therefore conflicting locations. This has to some degree been taken into consideration in the DSM, but if the module is further extended this should be more thoroughly evaluated. By dividing the cargo deck into a grid system and giving each module coordinates for their location on the deck, it is possible to establish conflicting modules early in the process as well as optimizing the equipment's general arrangement on the deck for modular capabilities.

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APPENDIX I – DETAILED GRAPH DATA FOR CONVERSION

	OP1	OP2	OP2 Decreased	OP1 Decreased	
Initial cost	0	-646400	646400	0	
Day rate	22000	58000	58000	22000	
Days			0		
0	0	-646400	-646400	0	
1	22000	-588400	-588400	22000	
2	44000	-530400	-530400	44000	
3	66000	-472400	-472400	66000	
4	88000	-414400	-414400	88000	
5	110000	-356400	-356400	110000	
6	132000	-298400	-298400	132000	
7	154000	-240400	-240400	154000	
8	176000	-182400	-182400	176000	
9	198000	-124400	-124400	198000	
10	220000	-66400	-83800	226600	Decreasing point
11	242000	-8400	-43200	255200	
12	264000	49600	-2600	283800	
13	286000	107600	38000	312400	
14	308000	165600	78600	341000	
15	330000	223600	119200	369600	
16	352000	281600	159800	398200	
17	374000	339600	200400	426800	
18	396000	397600	241000	455400	
19	418000	455600	281600	484000	
20	440000	513600	322200	512600	
21	462000	571600	362800	541200	
22	484000	629600	403400	569800	
23	506000	687600	444000	598400	
24	528000	745600	484600	627000	
25	550000	803600	525200	655600	
26	572000	861600	565800	684200	
27	594000	919600	606400	712800	
28	616000	977600	647000	741400	
29	638000	1035600	687600	770000	
30	660000	1093600	728200	798600	
31	682000	1151600	768800	827200	

APPENDIX II – CONCEPT COMPARISON

Attribute	Modular OSV	Multi-purpose	Conventional
Build cost and time	**Poor** - Large vessel complicates system solutions	**Medium** - Large vessel, less complicated system solutions and no need to prepare for module exchange.	**Good -** Smallest vessel of the three, less complicated solutions
Mission-specific efficiency	**Medium** - Modular capabilities offer relatively custom solutions to each operation.	**Low** - Designed to perform a large range of operations, the "golden mean".	**High** - Only equipment to perform a specific mission.
Hull efficiency	**Medium** - Some excessive modules, but quite mission specific modules.	**Low** - Excessive modules for each operation.	**High -** Only equipment to perform a specific mission.
Operational flexibility	**High** - High variance between operations	**Medium** - Smaller range, but still performing a set of operations.	**Low**- Very mission specific.
Operational costs	**Good -** see chapter Costs	**Poor -** Large vessel, with excessive modules for some operations increases the operation l costs.	**Medium -** Smaller vessel, fewer equipment modules.
Maintainability	**High** - see chapter Concept Evaluation	**Low** - Requires downtime to maintain modules.	**Low** - Requires downtime to maintain modules.
Availability	**High** - The essence of modular capabilities, can always deliver correct type of vessel with correct capabilities.	**Medium** - Some flexibility in operations.	**Low** - Requires a specific operation in order for being available for the market.
Mid-life upgrade and secondhand value	**High** - Solutions that are receptive for new modules and less effort in a future upgrade. Higher secondhand value due to higher operational flexibility and receptiveness for new modules.	**Medium** - None specific advantage of disadvantage within this category.	**Medium** - None specific advantage of disadvantage within this category.
Emissions	**High -** Reduced fleet and higher utilization of the vessel.	**Medium -** Large vessel, with low hull efficiency.	**Medium -** Looses over modular vessel because of larger fleet.

APPENDIX III – OUTLINE SPECIFICATION

PART I

1. Purpose

1.1 The outline specification is a draft of the vessel's function capabilities required by the Customer. It establishes the technical characteristics needed/desired on the vessel required by the Customer. It shall give the designer a review of which capabilities the vessel must be designed for. The designer shall propose a set up for the modular flexibility. A standard outfitting for the vessel shall be defined with the possibility to convert to other equipment configurations.

2. Type of vessel

2.1 The vessel is intended to perform several operations determined by the customer at the time. It shall be designed in a modular matter allowing for high operational flexibility. The replacement of equipment modules shall be given time requirements in form of hours, days, weeks etc.

2.2 Primarily built as: Construction vessel

2.3 Secondary designed to execute following operations: Anchor handling, towing, pipe lay operations and support missions.

3. Class Requirements

3.1 The vessel must be classified by one of the following class societies:

- BV – Bureau Veritas
- DNV – Det Norske Veritas
- LRS – Lloyds Register of Shipping

4. General Requirements

4.1 When the vessel is handed over to Customer it must be fully equipped and fully capable to carry out its role. This includes the equipment needed to perform secondary operations.

4.2 The vessel should be designed to operate in weather conditions, both on the Brazilian continental shelf and the Norwegian continental shelf.

4.3 The vessel must be equipped with a command and control center facing deck work area, capable of controlling all primary and secondary operations.

4.4 The propulsion system must be designed so that if any of the main drives goes down, no more than 35% of the maximum continuous aggregate rate considered in reaching total Bollard Pull will be lost.

4.5 It is desirable that the vessel has high endurance and it must be able to achieve relatively high cruising speed. This is to reduce time in transit for module exchange operations and emergency preparedness missions.
4.6 The vessel's main dimensions are to be determined by the highest criteria from the desired operations. There should be a cost/benefit evaluation when deciding main dimensions from equipment modules.

PART II

Operational Requirements

Operational requirements are divided into two categories, primary operations and secondary operations. Primary operations are defined as the operations that the vessel is capable to carry out without further re-construction. Secondary operations are those operations the vessel are designed for and are able to carry out after smaller and/or more extent re-construction. Both categories are intended as long-term outfitting (longer contracts, up to several years), but smaller equipment modules and functions should and will be exchanged on shorter prospects (depending on availability, but can be down to months). The time interval for exchanging a module must be defined and considered from a cost/benefit point of view.

1. Primary Operations

The vessel is to operate as a **construction and support vessel** (CSV). It shall have capabilities to provide the following multi-function support facilities.

- Sub-sea Construction
- Top side Construction
- ROV support for sub-sea construction
- Transport fresh water, diesel oil and deck cargoes, support operations

2. Secondary Operations

The vessel should after re-construction be able to carry out the functions which are listed below.

Anchor Handling and Towing

- Anchor handling support for rigs
- Tow/Move of Rigs

Pipe Lay

- Installation of sub-sea pipes

Support

- Cargo/Equipment transportation
- Transport fresh water, diesel oil, deck cargoes, bulk cargoes (cement/Barites/Bentonite) liquid mud, stores, materials & equipment
- Personnel transportation
- Standby(Fire and oil spill)/Rescue

APPENDIX IV – EQUIPMENT MODULES

Operations	A-Modules	B-modules
Construction		
	Main crane (Heave compensated)	Auxiliary cranes (rail cranes)
	Construction tower	ROV Hangar
	Moonpool	ROV Launch and Recovery system
	Large deck area	Extended accommodation
Anchor handling		
	Anchor winch	Auxiliary cranes (rail cranes)
	Stern roller	
	Shark jaw	
	Main crane (Heave compensated)	
	Storage room for chains and ropes	
	Large deck area	
Towing		
	Towing winch (Anchor winch)	
	Towing pins	
Pipe lay		
	Pipe storage area on deck	
	Ramp fleeting and elevation system	
	Main crane (Heave compensated)	
Support		
	Main crane (Heave compensated)	Auxiliary cranes (rail cranes)
	Large deck area	External FiFi system for fire fighting
	Storage tanks for dry and liquid bulk	Extended accommodation
		Oil recovery equipment

APPENDIX V – EQUIPMENT DESCRIPTION

Only those modules where the design of the module is not self-explanatory are included in this appendix.

1. Large deck area:

Large deck area is in fact not a module in itself, but has been included in the model because it is a driving design factor and is necessary for many of the operation.

2. Extended accommodation

The extended accommodation is a containerized module with all necessary equipment and luxury inside, depending on the size of the module the module can work as accommodation for a large number of crew. The module can be placed anywhere on deck and as long as it is possible to mount the module on deck with standard interface.

3. Towing winch

It is assumed that the same winch used for anchor handling can be used for towing operations.

4. Pipe storage area on deck

Pipe lay operations require storage possibilities in order to store the many meters of cables. The pipes are stored on large reels or carousels which can be placed anywhere on deck. The vessel will need a large crane to move the reels into deployment position in front of exit ramp. A simple interface between deck and pipe reel will keep the pipe reel steady on deck.

5. Ramp fleeting and elevation system

The exit ramp controls the exit angle and elevation for the pipes when entering the water. This is a simple ramp at the rear of the vessel. It is important that the ramp keeps the pipes clear from all hazards such as thrusters, hull structure etc.

6. Storage tanks for dry and liquid bulk

The storage tanks for dry and/or liquid bulk are planned as containerized module with dedicated slots on the vessel, either on deck or below deck. The number of tanks will depend on the size of the container.

APPENDIX VI – DESIGN STRUCTURE MATRIX

Operations:	Construction						Anchorhandling				Towing	Pipelaying		Support				
Modules:	Subsea Installation	Topside installation	Equipment handling	Accomodate extra personell	Equipment storage	ROV Support	**Deployment of anchors**	**Retrivel of anchors**	**Store excessive chaines & ropes**	**Anchor handling on deck**	Towing	**Deploy pipes from ramp on deck**	**Pipe reel storage on deck**	Accommodate extra personell	Store and transport equipment/cargo	Fire fighting/oil recovery		
Heave Compensated Knucleboom	1	1	1				[2]					4			[5]			
Equipment Handling Tower/Construction Tower	1																	
Moonpool	1					[1]						[4]						
Cargo Deck Area	1	1	1		1		2	2		2		4			5			
Auxiallary Cranes e.g. Rail Cranes	[1]		1		1					2		[4]			5			
ROV Hangar	[1]					1			x							[5]		
ROV Launch and Recovery	[1]					1			x							[5]		
Extended Accomodation				1										[5]				
Anchor winch						x	2/x	2			3							
Sternroller							2	2						x				
Shark Jaw							2	2										
Storage room for chains and ropes									2							x		
Towing pins											3							
Ramp fleeting and elevation system										x		4						
Storage for pipe reel													4					
Storage tanks for dry and liquid bulk												x			5			
External Firefighting system																[5]		
Oil recovery equipment																[5]		
	Heave Compensated Knucleboom	Equipment Handling Tower/Construction Tower	**Moonpool**	Cargo Deck Area	**Auxiallary Cranes e.g. Rail Cranes**	ROV Hangar	**ROV Launch and Recovery**	Extended Accomodation	**Anchor winch**	Sternroller	**Shark Jaw**	Storage room for chains and ropes	**Towing pins**	Ramp fleeting and elevation system	**Storage for pipe reel**	Storage tanks for dry and liquid bulk	**External Firefighting system**	Oil recovery equipment

APPENDIX VII – MODULAR COMPLEXITY DESCRIPTION

Equipment modules	**Technology readiness level**	**Degree of installation complexity**	**Modular space potential**
Heave compensated knuckle boom	**Medium** - Large module, difficult to achieve adequate strength	**Medium to High** - plug & play issue, Requires necessary hull strength & space, needs external support	**Low**
Equipment handling tower/Construction Tower	**Low to Medium** - Very large module, need exterior handling equipment	**High** - Large and heavy, need external support	**Low**
Moonpool	**Low** - Large module. Difficult to regain max strength if moonpool extracted. Possible extractable deck.	**High** - Difficult to "remove", Bus modularity might be applicable. Hard to exploit full volume potential, needs external support	**Medium -** Can be closed and used for storage
Large deck area for equipment storage	**Medium** - hulls are built in modular parts already. Deck can be divided into parts.	**High**- Dependent on other modules installed, requires great reconstruction.	**Low**
Auxiliary Cranes: Rail cranes	**High -** Slot modularity applicable	**Low to Medium** - Plug and play challenge, highly integrated system. Simple physical installation is possible	**Low**
ROV Hangar	**Medium to High** - Slot modularity should be applicable	**Medium** - Relatively small, can be handled by vessel on its own	**Medium -** Can be used for storage
ROV Launch and Recovery	**High** - integrated in ROV Hangar?	**Medium** - Can be introduced as an own module or from ROV hangar. Can be handled by the vessel itself	**Low**
Extended accommodation	**High -** requires only space	**Medium -** Relatively large module, but standardized, "containerized"	**Medium**
Anchor winch	**Low** - Large module, must withstand heavy tension. High effect on	**High** - Heavy and complex. Will most likely need external support. Highly complex	**Low**

	hull strength	integration	
Sternroller	**Medium** - Easy to replace, little effect on hull strength in general	**Medium** - Bus modularity, Small module, vessel capable of install without external support. Independent module	**Low**
Sharkjaw	**High** - Bus modularity highly applicable	**Low** - Retractable configuration of bus modular block if other configurations is needed	**Low**
Storage room for chains & ropes	**Medium** - Can use moonpool or other location as storage room for different storage requirements	**High** - Below deck requires extensive conversion and external support	**Medium** – Can be used for different storage?
Towing pins	**High** - Bus modularity highly applicable	**Low** - Retractable configuration of bus modular block if other configurations is needed	**Low**
Ramp fleeting and elevation system	**Low to Medium** - Large module highly advanced.	**Medium to High** - Handled by vessel or at supply station, needs sufficient space	**Low**
Pipe storage for deck (Deck reel)	**High** - Slot modularity applicable, requires deck area, (Considered modular today?)	**Low to Medium** - Handled by vessel or at supply station, needs sufficient space	**Low**
Storage tanks for dry & liquid bulk	**Medium** - Can use moonpool or other location as storage room for different storage requirements	**Low to Medium** - Bus modularity is possible, can be handled by vessel itself, and needs volume for tanks. Below deck = external support	**Medium** - Can be used to oil spill storage in emergency
External Firefighting system	**Low** - Not considered modular. Complex module.	**High** - Difficult piping and pumping systems required at all times	**Low**
Oil recovery equipment	**Medium to High** - Can be considered modular now.	**Medium to Low** - Easy installation, requires oil spill storage	**Low**

APPENDIX VIII – VESSEL INFLUENCE DESCRIPTION

Equipment modules	**Footprint loss**	**Vessel dimensioning**	**Stability**
Heave compensated knuckle boom	**Low**- Low area, usually located at either sides of deck	**Medium to High** - sufficient strength in deck to lift large modules	**High** - Extensive additional moment at sides when in operation
Equipment handling tower	**High** - Very large module, placed in operational area	**High** - Affects hull length, breadth and deck strength	**High** - Extensive additional weight, center placed close to mid-ships
Moonpool	**High** - Requires to fit large subsea modules, in operational area	**High** - Affects hull length, breadth and deck strength	**High** – High effect on vessel stability. GM, buoyancy etc.
Large deck area for equipment storage	**High -** Large, placed in operational area	**High** - Affects hull length, breadth and deck strength	**Low**
Auxiliary Cranes: Rail cranes	**Low** - minimal footprint loss in a non-operational area	**Medium** - Sufficient rail strength is adequate	**Medium** - Medium moment at sides when operating.
ROV Hangar	**Medium** - Medium footprint loss, flexible location	**Medium** - Affects mainly hull length and breadth	**Medium** - Dependent on location, placed at sides creates extra momentum
ROV Launch and Recovery	**Medium** - Medium footprint loss, flexible location	**Medium** - Affects mainly hull length and breadth	**Medium** - Dependent on location, placed at sides creates extra momentum
Extended accommodation	**Medium to High** - Many workers, not located in in operational area	**Medium to High** - Affects hull length and breadth	**Low to Medium** - Location dependent
Anchor winch	**High** - Large module, placed in operational area	**High** - Affects hull length, breadth and deck strength	**Medium to High** - Large and heavy module that will need additional deck strength. Center mid-ships

			placed.
Sternroller	**Low** - minimal footprint loss in a non-operational area	**Low to Medium** - Must bear pressure from lifting anchor	**Low** - Small module center placed
Sharkjaw	**Low** - minimal footprint loss in a non-operational area	**Low to Medium** - Must bear pressure from holding anchor (Deck strength)	**Low** - Small module center placed
Storage room for chains & ropes	**Medium** - Medium space requirements below deck structure	**Medium** - Adequate space below deck structure (Hull length, breadth)	**Medium** - Additional weight in storage equipment
Towing pins	**Low** - minimal footprint loss in a minor operational area	**Medium** - Must bear pressure from towing, deck strength	**Low** - Small module center placed
Ramp fleeting and elevation system	**Medium** - Large ramp, medium space occupation in operational area.	**High** - Affects hull length, breadth and deck strength	**High** - large and high center of gravity (COG)
Pipe storage for deck (Deck reel)	**Medium to High** - Depending on amount, large modules, flexible location.	**Medium** - Affects hull length and breadth, might also affect deck strength	**High** - Large and heavy module, additional weight
Storage tanks for dry & liquid bulk	**High** - Large space, can be stored on or below deck	**Medium** to High - Affects hull length and breadth	**Medium** - Centered and low COG
External Firefighting system	**Medium -** Small module, pumps and pipes can uptake more space	**Low to medium** - Some increase due to piping and pumps	**Low -** Minimal weight increase
Oil recovery equipment	**High** - Large module and requires space to store oil spill	**Medium** - Module in itself low, but requires storage for oil spill	**Low to Medium** - Sufficient stability when storing oil spill is important