NTNU

Norwegian University of
Science and Technology

Master's degree thesis

IP501909 MSc thesis, discipline oriented master

Title:Intelligent Library Of Offshore Vessel Equipment —From Mission Requirements to A Virtual Arrangement

Candidate(s) number/Author(s): 1102 / Tian Xu

Number of pages including this page: 98

Aalesund, 3rd June, 2016

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ABSTRACT

The topic of this thesis is Intelligent library of offshore vessel equipment, from mission requirements to a virtual arrangement. The objective of this study is to generate the corresponding alternative equipment arrangement design solutions by developing a data-based library, and further make comparison among those solutions to select a relatively better equipment arrangement design solution through essential evaluation method. Alternative arrangement design solutions will be made in 2D by a web-based APP while a virtual 3D arrangement prototype will be simulated in Siemens-NX.

This report is mainly divided into three categories: background, methodology development, case attempt. The background gives a brief introduction regarding to the expectation of the intelligent library along with some advanced concepts such as product architecture, product platform and modulization, which will be beneficial for constructing the intelligent library.

The methodology of the intelligent library is developed in the second part. The conceptual design of the intelligent library is defined in the early stage, along with the confirmation of the scope of the data-based library. The core idea of the intelligent library is developed by utilizing some advanced concepts including product architecture, product platform and modulization. Further, the specific process algorithm is created and implemented by applying some special methods inside (like equipment compatibility matrix) in order to make some balances in each potential equipment arrangements.

For evaluating the feasibility of the intelligent library, a case study is performed by following the 6-step process algorithm. Essential assumptions have been made in advance in order to operate the whole procedure much more swimmingly. Eventually, four potential design solutions are proposed while one of them is evaluated and stand out as a relatively better equipment arrangement design solution. Furthermore, the corresponding 3D prototype of the better arrangement is made in order to give both ship designers and ship owners a more comprehensive visual feeling about the layout of the arrangement.

Last but not least, some deficiencies in relation to the methodology and simulation are identified and summarized, along with the further prospects regarding to the improvement of the intelligent library.

PREFACE

This master thesis was written as part of my Master of Science degree in Product and System Design at the Norwegian University of Science and Technology, NTNU, during the spring of 2016, under the guidance of Professor Henrique M. Gaspar.

The thesis aims to construct a data-based library which is used to generate the alternative equipment arrangement design solutions according to the various mission requirements and form a relatively better arrangement design comparing the others. Three sections are included in the thesis, first comes with the formation of the problem, and the corresponding methodology is then described and developed. Further, the methodology is applied in a case study in order to see the feasibility of the intelligent library.

First and foremost, I would like to thank my supervisor, Professor Henrique M. Gaspar, for providing me with both valuable chance to have a collaborative work with Ulstein and also guidance throughout the whole process of this master thesis.

It's been such an amazing and unforgettable chance for me to study this topic and write my thesis. I have learned lots of valuable things during the whole process: how to make the theory practical, how to make the combination of advanced technology and apply it into methodology and how to apply the methodology into a real case. Last but not least I have learned the knowledge regarding to the product platform, module design and product architecture. Besides, my understanding with regard to the offshore support vessel design and operation is widened and deepened through this study.

Finally, I would like to thank my school and classmates for giving me such a precious memory for both studying and living.

Ålesund, June 3rd 2016

Tian Xu

Ålesund, June 2016

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ABBREVIATIONS

NTNU	Norwegian University Of Science And Technology
OSV	Offshore Support Vessel
AHTS	Anchor Handling, Towing And Supply Vessel
PSV	Platform Supply Vessel
DSV	Diving Support Intervention Vessel
OWSV	Offshore Wind-Lifter Supply Vessel
CSV	Construction And Support Vessel
IMO	International Maritime Organization
HHI	Hyundai Heavy Industries
SPA	Scalable Product Architecture
DSM	Design Structure Matrix
AAMIS	Associative Analysis Of The Mission
MMRT	Mission-Modules Relationship Table
ROV	Remotely Operated Underwater Vehicle
2D	Two-Dimensional
3D	Three-Dimensional

1 INTRODUCTION

1.1 General overview

1.1.1 Offshore support vessel

Norway has a long maritime history for more than 150 years, and it has been a major player on the world's oceans. Locating on the fringe of Europe, by having less than a thousandth of the world's population, Norway has turned out to be one of the world's largest merchant fleets. In 1971, the Norwegian petroleum production get started by developing the Ekofisk field, and since then it has grown rapidly.

The Norwegian maritime industry is a complete cluster comprising leading shipping companies, shipbuilding yards, equipment manufacturers, designers, service providers, universities, research and development centres and regulatory bodies. In 2009, the Norwegian maritime industry became Norway's second largest export industry, which accounted for 5.5% of Norway's GDP. The Norwegian maritime cluster keeps developing and optimizing new, innovative and suitable solutions which makes Norwegian fleet becomes one of the most modern and advanced in the world.

Offshore oil and gas exploration and production are regarded at the forefront of the world's leading economic activities in the late 20th century. For exploring these resources, a tremendous industry has developed by employing floating drilling rigs, ships and fixed platforms, and these diverse units contribute to the appearance of a range of vessel types, which designed for supplying the support operations those units required, and it is collectively called offshore support vessels (Richard White, 2004).

Today, Offshore support vessels (OSVs) are viewed as one of the most significant and potential vessels in the world. They are defined as transmitting cargos, persons to the offshore platform and assisting the operations at sea. Generally, OSVs could be divided into several specific types of ships according to different kinds of functions like AHTS (Anchor Handling Tug Supply), PSV (Platform Supply vessel), DSV (Diving Support Intervention Vessel), OWSV (Offshore wind-lifter Supply Vessel) and so forth. Normally, the size of these kinds of vessels ranges from 50 m to 110 m in length.

Recognizing as the main operators of offshore support vessels, ship owners either employ these fleets to do their own unique specific missions or operate such vessels with other activities such as towage and salvage, conventional ship owning, or other industrial and business activities

(Richard White, 2004). Mission requirements should be stated in details by ship owners so that the corresponding specific OSV could be provided to supply the service to the project.

1.1.2 Mission and equipment

The general mission for OSVs is to support and assist the offshore oil and gas exploration and production. This can be decomposed to a lot of different types of specific missions. Normally, a vessel is assigned to do a single mission, whereas it is much more common and competitive for ship designers to generate a ship design solution which makes the vessel achieve two or more mission requirements simultaneously, and this is beneficial for ship owners as well. However, ship owners and designers should reach an agreement on the balance of all mission-solving capabilities in a vessel.

Figure 1-1 Potential mission for offshore vessel

OSV Mission requirements demanded by the ship owners are matched to the vessel performance available by various kinds of mechanisms, which is usually called as equipment. It determines the mission-solving capabilities of the vessel because different combinations of equipment in the vessel would help the vessel to operate different performance. For instance, four distinctive potential missions of OSV are shown in the four corners of Figure 1-1, and the vessel in the centre represents a common type of OSV. All of the four OSVs assist the offshore support operations, whereas each of them has their own specific task. The four tasks seem so far from one to the other whereas they do have one thing in common—the mission performed by the vessel is relied on the equipment on board. The OSV could perform different kinds of missions by equipping different combinations of equipment, which, can be seen in Figure 1-2, all the equipment shown in the four corners are potential equipment of OSV, and with the installation of the equipment, the vessel can be defined to do various missions.

Figure 1-2 Potential equipment on board

Inside a common ship design process, it takes lots of time for ship designers to make equipment arrangement according to the diverse mission requirements. Therefore, generating a method which can make a rapid mission-to-arrangement solution seems to be a potential subject of interest either for ship designers and ship owners.

1.2 Intelligent library definition

The objective of the underlying study intends to create a rapid mission-to-arrangement solution by constructing an intelligent library of offshore vessel equipment based on the deployment of mission requirements, aims to help both shipyards and ship designers to save the lead-time and cost. The methodology proposes the equipment division based on its functionality or capability. The equipment would then be analysed in relation to the dependencies level with mission requirement (design structure matrix), interactions between equipment would also be studied in order to improve the efficiency of arrangement process, which, could as a result of increasing the efficiency of ship design procedure. By using the data (equipment) that stored inside the library, the intelligent library is then able to figure out the potential equipment-arrangement design solutions according to various mission requirements.

The core idea of constructing an intelligent library instead of building up a data-based library is embodied in the aspect of 'Automatic assemble', 'Rapid' and 'Collision-solving'.

1) Automatic assemble

   The intelligent library proposes a modular approach to make a virtual arrangement of vessel equipment, substituted by ship modules or blocks which are sketched based on the specification of each equipment. Extracting the key equipment-related information according to the mission requirements, the intelligent library would then work as a smart tool to pick out the corresponding modules (equipment). The design structure matrix will be applied inside the module-selection process in order to show how essential each module is for operating the required capability, and the designers would then discuss and reach an agreement with ship owners regarding to the confirmation of equipment-selection. Further, the intelligent library would generate different kinds of design solution by composing these units in different ways.

2) Rapid

   In shipbuilding history, ship design is an individual process, and the products are always developed one at a time (O.J Mork, 2014). Therefore, it takes lots of time to make the arrangement according to different kinds of situation. Comparing to the traditional ship design solution, intelligent library would take far shorter time to create various arrangement-solutions expressed by a virtual arrangement.

3) Collision-solving

   Inside these modules (equipment) which viewed as a potential unit for performing the required mission, there may exists collision between two or more modules. Reasons for having this kind of conflicts could either due to the location overlap or unsatisfy the stability requirements once these modules are installed and operate simultaneously. Similarly, the selection of a module (equipment) can also contradictory to the capability that we want to perform. For instance, offshore wind lifter support is the given mission, to install a main deck crane is unpractical as it occupies the location of wind lifter system, which would be considered as a negative module (equipment) because the accurate mission-required module—wind lifter system would be impossible to be equipped on board once the main deck crane is installed, and it would fail the mission.

Thus, it is necessary to study and apply the DSM and equipment compatibility matrix, interactions between modules (equipment) and interactions between modules (equipment) and missions would then be figured out clearly. It would help improve the he efficiency of arrangement process by rapidly filter the useless arrangement solutions.

1.3 Problem formulation

During the process of generating a ship design solution, ship owners would have various specific requirements regarding to functionality, vessel dimensions, serving-area and so forth, which is supposed to be followed by the ship designers. For instance, Figure 1-3 indicates four potential OSV missions in Ulstein, by adding more specific information like functionality, basic dimensions and some other requirements, they would form the 4 different kinds of missions (PSV; SV; AHTS; OWSV).

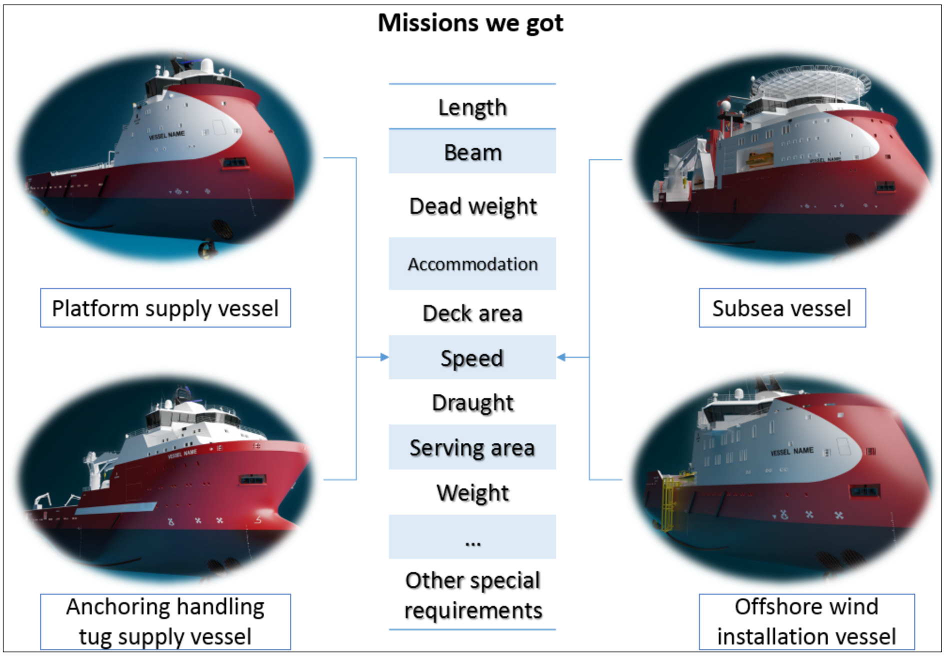

Figure 1-3 Various potential mission requirements

Figure 1-4 presents some of the equipment or systems that Ulstein owned, it would then be a problem for arrange these systems according to diverse specific mission requirements in a rapid way, and it is the reason for constructing the intelligent library.

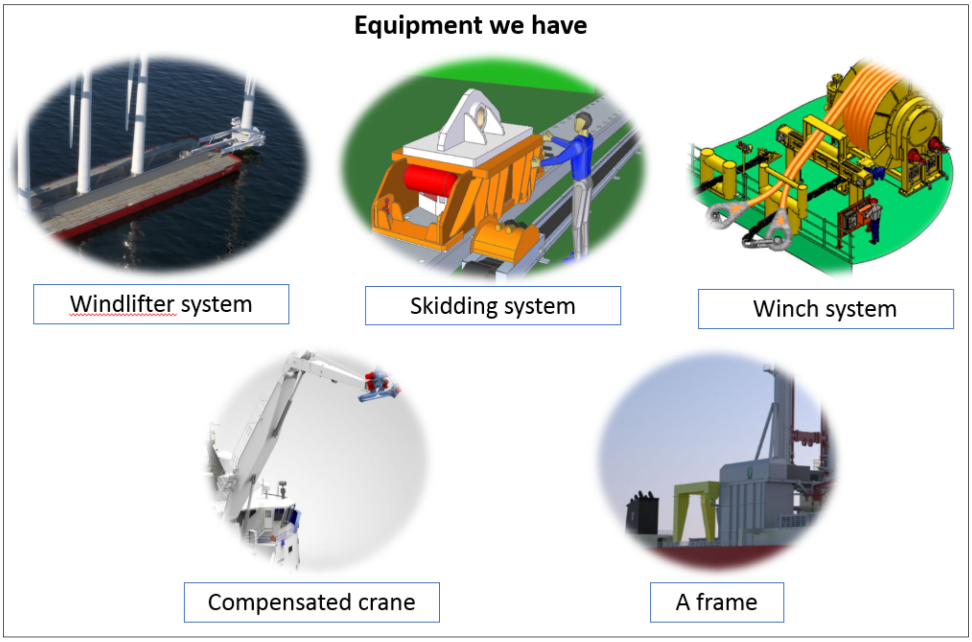

Figure 1-4 Equipment equipped in shipyard

1.4 *Scope*

The general design scope is presenting by three circles, see as Figure 1-5, representing three different items: OSV Mission, OSV arrangement and Intelligent library.

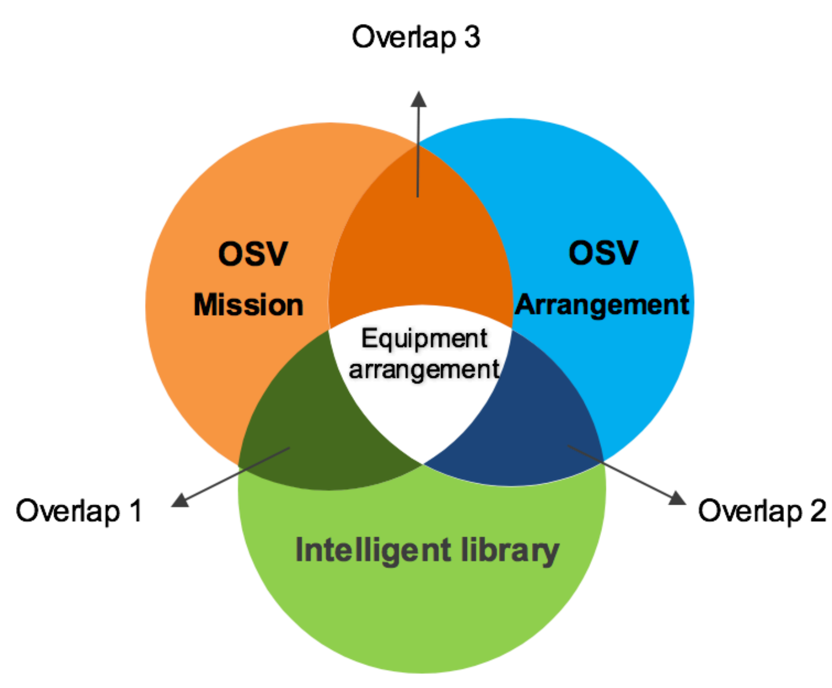

Figure 1-5 Idea of intelligent Library

The overlap does exist between each two items, and following comes the specific explanation for the 3 overlaps:

- **Overlap 1**

  In order to run the intelligent library, a certain amount of equipment or system should be stored inside to turn the library into a real data-based library. Refining from the OSV mission which is specified for the OSV, specific mission requirements regarding to the tasks, functionality, performance would be found defined and stated by the customers, which, is the criteria for ship designers to generate proper ship designer solutions. Inside the library which stored numerous equipment, there are some units that are essential or suitable for the OSV to be installed in order to satisfy the mission requirements, and these units comprise the overlap 1.

- **Overlap 2**

  OSV arrangement includes numerous parts such as hull structure, outfitting, machinery, sea keeping and station keeping (Erikstad & Levander, 2012). Utilizing the equipment which is capable of being equipped in the vessel, different kinds of equipment arrangements can be made by essential selection from the library and proper assembling, and these equipment arrangements are part of the whole OSV arrangements. Nevertheless, those equipment arrangement-solutions defined the overlap between 'Intelligent library' and 'OSV arrangement'

- **Overlap 3**

  Recalling from 'overlap 1', Extracting from the OSV mission, specific mission requirements are earlier defined and stated by the ship owners or operators. Normally, it takes a lot of time for the ship designers to generate the ship arrangement solution that satisfy the mission requirements. All kinds of arrangements (like hull structure, outfitting, machinery, sea keeping and station keeping) compose the 'overlap 3'

Further 'upgraded overlap' can be found among these three overlaps, which, is named as 'equipment arrangement' in Figure 1-5, and this is because the concept of 'equipment arrangement' exists in each 'overlap' once special decomposition is made inside.

- For 'overlap 1'

  Even though there may be numerous equipment which satisfy the mission requirement, not all of them can be organized and assembled in one arrangement. For instance, 'deck crane' and 'side crane-skidding system' are both suitable for the mission of 'AHTS', whereas only one can be installed due to the location occupy issue, decision has to be made before the arrangement. Once the ‘deck crane’ is selected to be installed on board, it would be classified into the ‘equipment arrangement’ part while equipment like ‘side crane-skidding system’ would be defined in the other part that has been colored in ‘overlap 1’.

- For ‘overlap 2’

  Division is also made in ‘overlap 2’ according to the specific mission requirement, lots of OSV equipment arrangements are generated based on the equipment stored in the library, whereas only a small amount of arrangement-solutions are found in accordance with the specific mission requirements. Therefore, those suitable arrangement-solutions are classified in the while part of ‘overlap 2’ while others belong to the colored part.

- For ‘overlap 3’

  Among all the arrangements that are specially designed according to the specific mission requirements, only one kind is fully make use of the equipment inside the data-based library. Others such as machinery system arrangement might use some systems like main engine and pump specifications, which are beyond the ability of intelligent library. Thus, ‘overlap 3’ can be divided into the part of ‘equipment arrangement’ (white part in ‘overlap 3’) and the other one (colored part in ‘overlap 3’)

The core idea of the intelligent library is to utilize the overlap among these three items, which, representing some of the equipment stored in the intelligent library that satisfy the mission requirements and will be further analysed to make suitable potential arrangement-solutions. The data-based library is named as ‘intelligent library’ instead of ‘library’ would then demonstrate one of the ‘intelligent’ part through selecting the relatively better arrangement-solution and further make a virtual arrangement.

2 Background

2.1 Offshore support vessel

Some people define the OSV as the vessel which are primarily engaged in the transport of stores, materials and equipment to and from mobile offshore drilling units, fixed and floating platforms and other similar offshore installations; whereas others think that OSV is the well-stimulation vessels, but excluding mobile offshore drilling units, derrick barges, pipe-laying barges and floating accommodation units, which are otherwise primarily engaged in supporting the work of offshore installations (IMO, 2007).

The prototype of offshore supply vessel (OSV) can be tracked to 1955, when Alden and John Laborde designed the first purpose oriented vessel which was used to supply offshore platforms, ever since that day, OSVs were growing steadily, especially in the past decades, due to the increasing oil and globalization, the demand for OSV grows mightily. An offshore report shows that the growth of PSV and AHTS's orderbook are respectively 23 and 7 percent in 2014.

Douglas-Westwood (2015) perceived that the oil price affects the offshore vessel deliveries with two-year lag. The petroleum truth report shows that the oil value has dropped from \$115 per barrel in 2014 to \$63 per barrel in 2015, and in recent days, it keeps on decreasing. If the correlation between oil price and offshore vessel deliveries persists in the coming years, we can expect a decrease of OSV orderbook in the years later. Fewer orderbook makes the market much more competitive, in order to secure a place in this industry, shipyards have to develop a design which is cost-saving, high quality and short production cycle.

Ulstein Group ASA is the parent company of a group of maritime companies, specializing in ship design and maritime solutions, shipbuilding, power and control and shipping. The family-owned company was founded in 1917. Ulstein played an indispensable role in the Norwegian ship industry, and it has made key contribution to help and remain Norwegian ship industry at the forefront. As one of the Norwegian universities, Ulstein started cooperation with Norwegian university of science and technology for some years, providing necessary data, collaborative information and opportunities for researchers and students. With the development of offshore industry, ship mission requirements are getting more complex and diverse while the market becomes more competitive with more shipyards appear, the importance of generating cost-effective and time-saving ship design solution is then highlighted in winning contracts for all ship design companies, including Ulstein.

The offshore vessel industry is characterized by product variation and customization, which, may bring an increase both in sales and costs, as shown in Figure 2-1 (Hildre et al., 2010). Each ship design solution is normally developed one at a time and these unique products have more limited use due to the complexity of highly customized mission requirements and inter-relationships between different segments (Erikstad, 2009). Therefore, the products are normally not designed in relation to reuse oriented, however, ship designers are accustomed to reuse the earlier analogous ship design drawings and models according to the latest mission requirements without concerning about the earlier mistake and corresponding improvements and modifications. New mistake is also easily to appear because of the unadaptable issue (Hildre et al., 2010). High dependencies of each parts inside ship design procedure may lead to sky-high cost resulting from the modifications, as a result, it is vital to define standardization inside ship design process if we want to reuse the previous models again and again for chasing high-efficiency ship design solution.

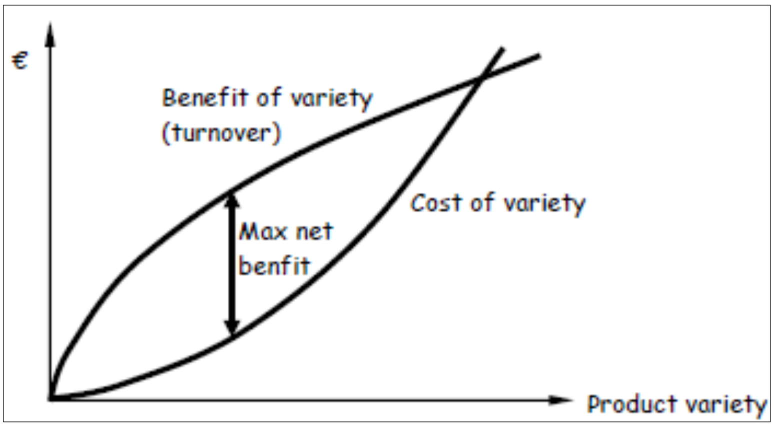

Figure 2-1 Product variety and customization (Hildre et al., 2010)

For analyse the location of intelligent library, specific ship design procedure is supposed to be studies in advance. Lamb (1969) has pointed out that in order to do effective control and planning, it is necessary that a standard design procedure should be adopted. As ship design involves a lot of repetitive calculations, much time can be saved by using the standard forms. Also, the use of standard forms could ensure adherence to the adopted procedure and make it possible to estimate the average time taken for each calculation in the procedure. Furthermore, this could assist ship designers and stakeholders to estimate the reasonable time required to complete the whole project. The proposed workflow of ship design procedure is as follows:

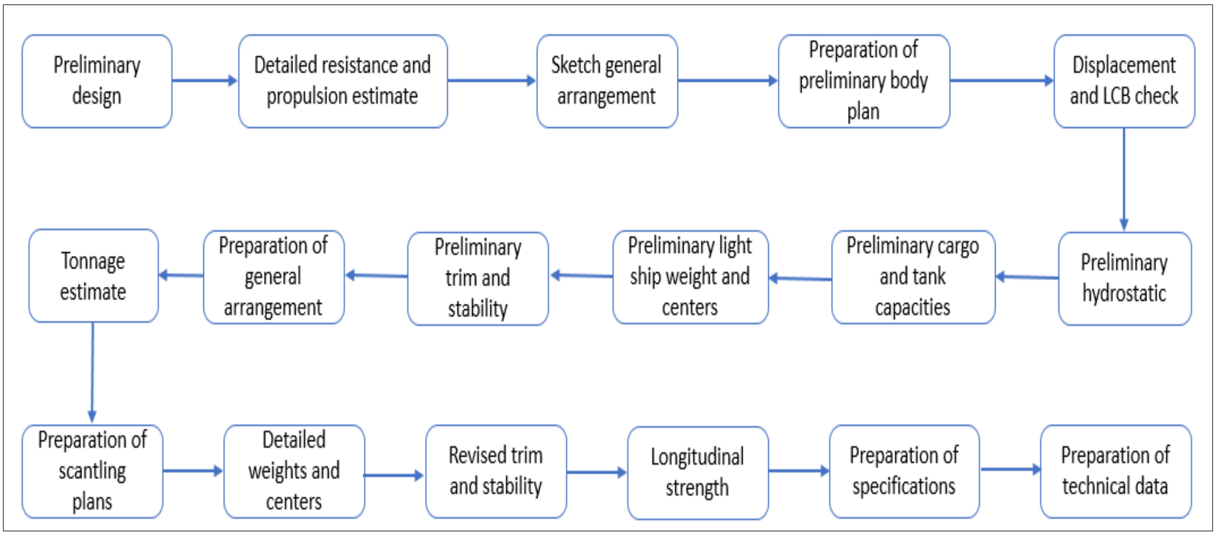

Figure 2-2 Ship design procedure

The complete ship design is to be prepared by a team consist of several designers, as T. Lamb (1969) described, the first three items in Figure 2-2 would be calculated by naval architecture while the remaining work would be further distributed to three different kind of designers.

For developing a cost-saving and time-saving design solution, ship design process has to be upgraded. According to Lamb (1969), ship design process can be divided into 17 parts. When we have a look at these steps in details, we may found out that there may be too many repetitive calculations in some steps, which, can be simplified and intelligentized.

Ship design project is usually completed by a team that maybe consist of hundreds of persons. If we want to develop the intelligent library inside the ship design procedure, the correlation between these steps should be figured out first. Like Lamb (1969) described, the first three items (Preliminary Design, Detailed Resistance & Propulsion Estimate and sketch general arrangement.) would always calculated by naval architecture in the proposed procedure. Therefore, comparing to the traditional ship design procedure, a lot of time and cost would be saved by developing the intelligent library here to help to accomplish the first three steps.

T. P. Mcdonald (2010) has made an attempt to develop a concept design method by employing a library based approach. The objective of the library is to generate several alternative potential ship design solutions based on limited library of possible design options. The library has to be constructed before the ship designers start the ship design procedure. The existence of the library is to assist ship designers to rapidly find out the suitable design solutions satisfy the mission requirements. The author put so much emphasis on the importance of ship requirements in the whole process, not only as a factor driving the ship design procedure, but also through the ongoing communication between ship designers and ship owners, as well as other stakeholders.

Tommelein (2006) summarized that the amount of components would cause matching problems because more options may appear. Besides, the existence of too much components inside a library would add the possibilities to make the process unmanageable or delay. The author stated that standard project should be developed in the early stage, or even before the start of a project. Relocating this knowledge into our study, offshore support mission can be decomposed into lots of different missions in specific, which means the mission-corresponded equipment would be too much, once all the equipment is input into the intelligent library, it would make the intelligent library hard to balance and easily to gum up the library system. Therefore, the definition of mission-corresponded equipment should be accurate and the appropriate controls of the amount of equipment are necessary in order to ensure the efficiency of the intelligent library.

Baldwin and Clark (2000) demonstrated that the principle of design should be confirm as early as possible because it affects the whole process. Interaction, which is another big issue in defining the standard components, these two authors suggested that in order to reduce the complexity of module design, interactions between components should be avoid when possible.

2.2 Conceptual design for intelligent library

According to T. Lamb, preliminary design stage is the ‘cornerstone’ of the whole ship design procedure, calculations inside this part aim to determine the dimensions, Hull form and others in order to satisfy the required speed, capacity and some other mission requirements. The minimum speed for the vessel to operate is one of the foremost requirements, it matters whether the whole ship design would success or not, and that is why detailed resistance and propulsion should be estimated after preliminary design. General arrangement is supposed to be sketched after those two parts, the position of bulkheads, decks, machinery space, superstructure and deckhouses must be defined and located.

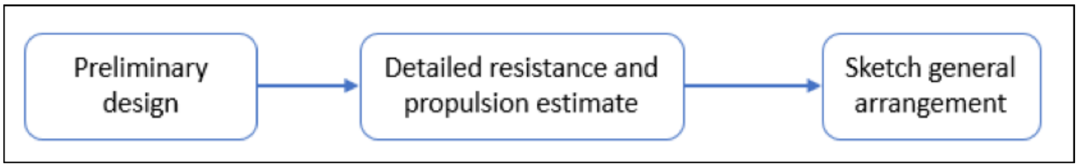

Figure 2-3 First three ship design phases

Normally, these three steps would take ship designers quite a lot time as there are too many repetitive work inside, thus the intelligent library could undertake some work to simplify and improve these process. Recalling the problem formulation, we could then focus our study on a small part inside these three procedures, and the main idea of the intelligent library is to sketch the equipment arrangement according the specific mission requirement by using the equipment or systems stores inside as a modules or blocks.

The conceptual design for intelligent library consist of three main parts: mission, mission requirement and arrangement. As Figure 2-4 shown, each mission is supposed to have its unique mission requirements, and the alternative arrangement solution would be generated after the input of various mission requirements. The core idea of intelligent library is to refine the key information from the ‘mission’ part, according to which the corresponding arrangements could be further made. Normally, in order to design an equipment-arrangement solution that is able to satisfy the mission requirements, it would take both ship designers and ship owners quite a long time, which is described as the black curve in Figure 2-4. However, with help of the intelligent library, which works as a bond to connect the ‘mission’ with ‘arrangement’ as it has overlaps with them respectively, corresponding arrangement-making solutions could be generated automatically after the input of unique mission requirements of each mission, and the methods employed by the intelligent library are sketched as orange line in Figure 2-4. Comparing to the traditional ship design solution, a lot of time and cost would be saved with the help of the intelligent library.

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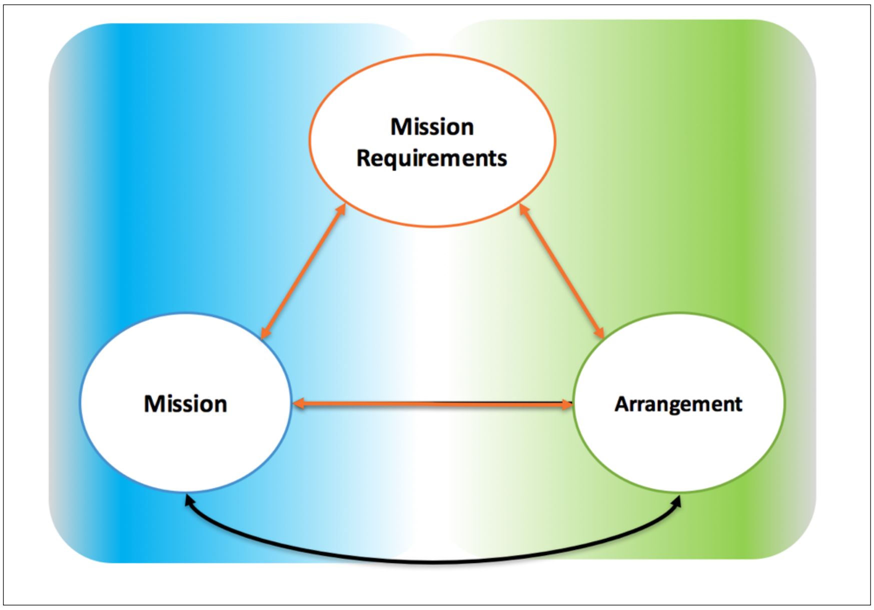


Figure 2-4 Conceptual design of intelligent library

2.3 *Advanced Concept introduction*

2.3.1 Modular architecture in ship design

Modular architecture has been applied into other field like software and car industry for quite a few years, and according to those successful applications, the main modules and interface are defined earlier in the architecture whereas the new modules are developed and added inside without affecting the main system afterwards. Customization and variation could then be achieved by modify the earlier modules and combined according to different requirements (Hildre et al., 2010). Hyundai Heavy Industries (HHI) has attempted to apply modularization in ship design and construction but failed to implement this method. Nevertheless, they made it possible to apply a standardization of parts on a low level of ship construction, which, still achieved purpose of main cost savings. In the long term, applying the modular architecture in product design process will be beneficial for design companies as a result of the reduction in time.

Modularization is usually described as a means for helping manage those seem complex demands while it has some special connections with the manufacturing concept of mass customization. Modularity has been studied for quite a few years, at the time when an integral product is ‘modularized’, it would be divided into several pieces or components, and those pieces or components would be further assigned to modules in detailed architecture. Normally, modules are replaced either by physical building blocks or non-physical objects like software (T.D Miller, 1998). Baldwin and Clark (2009) pointed out that applying the modularity in engineering could not only help make the complexity manageable, but it could also generate the possibility to run parallel work. Last but not least, the application of modularity helps to accommodate the future uncertainties.

In marine industry, due to the complex ship structure, modularity hasn't been widely used and promoted a vessel life cycle could be improved, upgraded and optimized by applying the modularization inside (Brekke 2012).

To apply modularization into ship design process has been proposed for many years, and a lot of ship designers tried to make it. According to the director of ship production at Hyundai heavy industries (HHI), they spent lots of time to study modularization and attempted this concept in modular hull structure in merchant vessels, and they expect to generate the ship modules with standard bows and sterns while the mid-body sections differs with each other. The attempt failed in the final because it affects the stability and hydrodynamic boundary condition so much. The complexity of ships and ship design process make it hard to make the definition of standardization and modularization, whereas proper use of modularization can have a positive effect on the whole ship design process such as decrease the lead time, which is so attractive for ship designers and other stakeholders. Therefore, it is vital to choose the location of module design.

2.3.2 Ulstein module design strategy

Ulstein built Ulstein A101 (offshore supply vessel) in 2002 by using the modular design strategy, and it is the first step for Ulstein to use modular design philosophy to build offshore supply vessel. The core of whole idea is the standardized components, substituted by ship modules, blocks and its specifications, which could be employed and reused in different design solutions, and that is environment-friendly and cost-saving. This strategy demonstrated that it is possible to design the simplest and most advanced ships by using standardized components.

2.3.3 Ulstein product platform strategy

Apart from the application of modularization, Ulstein has also studied about product platform concept, they have built up a product platform (as the shown in Figure 2-5) which serves for producing offshore supply vessels, with this platform, ship designers could configure unique ships according to various mission requirements. According to S.O Erikstad: *this attempt indicates that the design reflected in early specification phase should be as consistent as possible with the downstream detail engineering, and in the end production, with as little (re)work as possible*.

Figure 2-5 Ulstein has developed a modular production concept to achieve higher degree of standardlization and efficiency in production (Erikstad & Levander, 2012)

2.3.4 Product platform

Product platform concept, another technology that has been studied for long time, it is more likely the abstract skeleton where various customized modules are supposed to be configured (Erikstad, 2009). This unique technology was firstly applied in offshore industry through equipment production. Rolls-Royce attempted to combine it with module design concept to manufacture the deck machinery. This combination concept requires some redesign of present product lines by decrease the number of configuration elements, however, it made tremendous changes to Rolls-Royce not only in generating more possible configuration options, but also in reducing the costs and time (Andreassen, 2005).

The Volvo XC90, first vehicle to use Volvo new scalable product architecture (SPA) platform set. The SPA strategy is based on some vehicle modules combined a platform to form the basis for all Volvo models above V40 size. The core of SPA platform (as shown in Figure 2-6) is interface, as a part of the platform, those sections have common interface with each other, which help them to form a tightly integrated unit that called platform. However, the dimensions and material of the modules are flexible. Therefore, it is possible to outsource all or part of the sections and use the expertise to produce vehicles more efficiently and cheaply. Early in 2008, Veenstra has also presented a strategy that is based on using platform.

Figure 2-6 Volvo product platform strategy

2.3.5 Modularization plus product platform

The relation between modularization and product platform is interdependent. The product platform can satisfy various specific markets or mission requirements by adding, removing, modifying or scaling modules. The key factor to balance in the platform design process is between commonality and distinctiveness (Simpson, 2003), or between cost-cutting and increasing market shares (Ericsson and Erixon, 1999). Besides, in shipbuilding history, ship design is usually completed from scratch to the end, which implies the lack of long-term thinking, and the attentions are more focused the individual projects rather than the process improvements.

2.3.6 Virtual prototyping

Apart from these two concepts: modularization and product platform, there is another technology called virtual prototyping that assists to implement the product design process. Comparing to the real prototyping which is based on the conceptual design to build up a real physical product model, virtual prototyping requires the special design in a virtual way. Decision on whether to use real prototyping or virtual one depends on the different kind of products and situations, but both of these two methods aims to help ship designers and customers get a real feeling about how the product would be like (O.Chaves, 2015).

The 3D virtual prototyping developed in the early stages may affect the choice of design process. The utilization of virtual prototyping can lock the designers into their original assumptions, whereas it could also provide a platform for a visual, fast-feedback ‘design sketching’ environment (Alonso et al., 2013). Further, by defining the corresponding functionalities to the parametrically defined building blocks in a system-based model, the design templates would then update along with the mission requirements (Erikstad & Levander, 2012).

2.4 summary

Throughout these literatures, we could relocate the knowledge into our study:

- Ship design is a long and complex process which includes numerous different parts. Thus it is important to determine where to arrange the intelligent library. According to Lamb (1969) and Tommelein (2006), modularization should begin as early as possible.
- Product platform should be defined accurately, otherwise fewer projects are willing to share the costs of constructing a configurable product platform (S.O, Erikstad, 2009).
- The structure of ship is complex and there maybe thousands of equipment inside a vessel, so it is impossible to input all potential equipment inside the library. Inspired by Volvo module design strategy, special partition can also be applied in a vessel, therefore, ship could be divided into 2 parts: ‘platform’ and ‘mission’. The ‘platform’ is the basis of a vessel while the ‘mission’ is all models above the ‘platform’.

2.5 Further conceptual design for intelligent library

Based on the idea of connecting the mission to the arrangement, the concept behind ‘intelligent library’ did some extension. Unlike presented above, instead of directly connecting the ‘mission requirement’ part with ‘arrangement’ part, there are one more main module in this conceptual sketch, which, is ‘Intelligent library’ (as shown in Figure 2-7). Basically, the idea of the function of the library is more like a smart automatic assembly tool. At the time when the designer is told which kind of vessel is going to be built and tells the library, this library would perceive which equipment should be equipped in the vessel as a mandatory part while some equipment would be there as an option.

In order to operate the ‘intelligent library’ swimmingly, some preconditions are defined in advance. Since the library is going to work as a connection bond between ‘mission’ and ‘arrangement’, enough data (equipment and systems) should be stored inside so that it could pick up the useful components according to the mission. In addition, in the connection between ‘intelligent library’ and ‘arrangement’, there exists one more section that is named as ‘smart algorithm’, actually, it is one of the most significant part in the library to make it work in an intelligent way. Like mentioned before, the alternative arrangement design solution would multiply over a crowd of mission requirements without making any filtration. By having the ‘smart algorithm’, it would help to filter the unnecessary design solution and make the remaining ‘arrangement’ solution as smart as possible.

The upgraded conceptual design diagram of intelligent library is shown in Figure 2-7, starting from the ‘mission’ part, which contains a lot of various mission requirements defined by the ship owners or operators. Among those mission requirements, the key equipment-related requirements would be further extracted and send to the intelligent library. Numerous alternative arrangements that satisfy the mission requirements would then be made and proposed. However, as the concept of intelligent library is proposed as a smart assemble tool instead of just a data-based library, smart algorithm should be developed inside the intelligent library. By using the smart algorithm, the library would then select a better design solution among those alternative choices. At last, the ‘arrangement’ would send the design-method signal to ‘mission’ part, which works as a double-check.

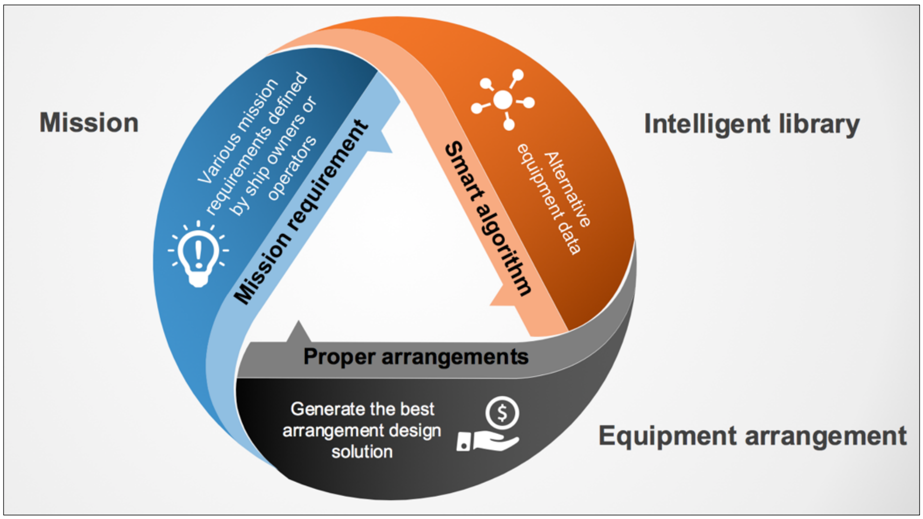


Figure 2-7 Further conceptual design for intelligent library

2.6 Utilization of advanced technology in intelligent library

2.6.1 Product architecture

Product architecture can not only make the definition of primary functionality of a product, but it could generate a direct view about the specific relationship inside. The product architecture is usually presented by a hierarchy framework, in which the functionality is always arranged at the top while the specific equipment or component are put at the lowest level. The main purpose to establish product architecture is to make the function-oriented hierarchy show all functions which are in relation to the product family (S.O, Erikstad, 2009).

OSV is the general product of this study, at the time when specific mission requirements are given, specific OSV type would be presented by then to supply the service to the project. The hierarchy framework intends to show the capabilities that the product (vessel) is supposed to operate. Anchor handling and platform supply are two typical capabilities for OSV to perform (see in Figure 2-8), each operation can also be decomposed into several specific operations, and these operations are viewed as terminal function and could therefore determine the corresponding equipment. For instance, the crane and stern roller have to be equipped in order to deploy anchor and do the towing operation.

The use of product architecture helps to figure out the relations between the function and equipment, and as the assumptions stated before, each equipment develops a function that cannot replaced by any other equipment, the product architecture assists to explain why each equipment should be stored in the library and what is the reason to enable it in an arrangement. Last but not least, the existence of product architecture eases off the load on the intelligent library and make it manageable.

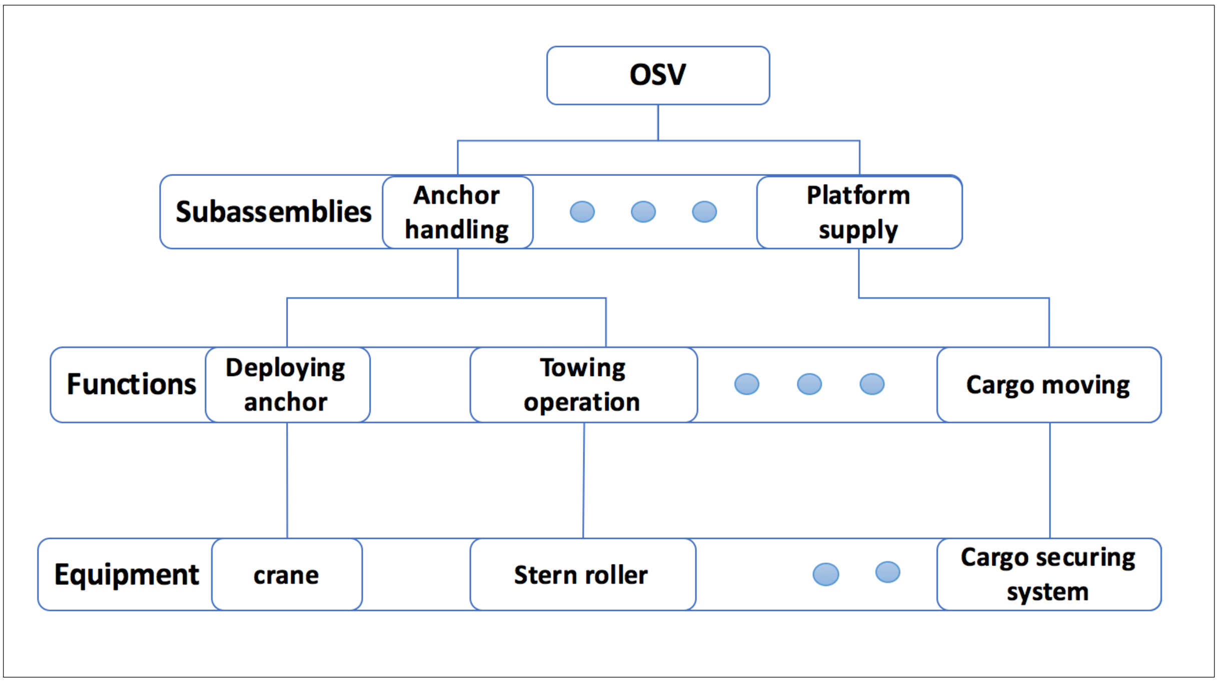


Figure 2-8 Product architecture illustration

2.6.2 Product platform applied into ship design

As T. P. Mcdonald (2010) indicated that the complexity of ship and the complexity of ship design process make it hard to develop an arrangement design that is able to satisfy the emergent mission requirement. The initial library should be large enough to contain all alternative potential equipment or system options that ship designers may interest, and it has to be established before the whole ship design process starts, the intelligent library would then assist the ship designers to pick up and assemble corresponding alternative equipment according to the mission requirement. However, as there may be thousands of equipment in the whole vessel, once all of them are input into the library, the combination options would soon grow up and make the library unmanageable.

The equipment range has to be narrowed down as a result of the unmanageable combination options issue. Inspired from the Volvo product platform strategy, we could then divide the vessel into two main part: ‘platform’ and ‘mission’ (like shown in Figure 2-9). S.O, Erikstad pointed out that ship design is an individual procedure, and fewer projects would share the cost of building up the configurable platform, unless it is beneficial for present and future projects. Therefore, vessel definition has to be made before establishing the platform. In this study, OSVs are selected to be analyzed as they are functionality-oriented.

The concept of product platform applied into ship design is shown as Figure 2-9, the ship product is mainly divided into two parts: mission and platform. As the main topic and objective are developing the intelligent library to do the equipment arrangement automatically according to the various mission requirements. Therefore, the intelligent library would mainly deign the arrangement solutions for the deck equipment, which, is described as the ‘mission’ part in Figure 2-9. The general mission for OSV is to support offshore operations, whereas each kind of OSV has their unique mission, and careful observation will find the functionality-related deck equipment is located in the ‘mission’ area. Once the equipment in ‘mission’ part changes, the OSV will develop some different functions. Also, there also has mission-related equipment in the ‘platform’ part, whereas it is neglected in order to simplify the whole procedure of intelligent library. Besides, for the purpose of simplify the platform, we hereby assume to replace platform with cargo deck, which could be better simulated in the virtual arrangement phase.

In general, it is feasible to establish a common scalable platform (cargo deck) for OSV, equipment could be configured by ship designers according to the future functionality requirement. The flexibility of vessel could also be increased by developing this special platform.

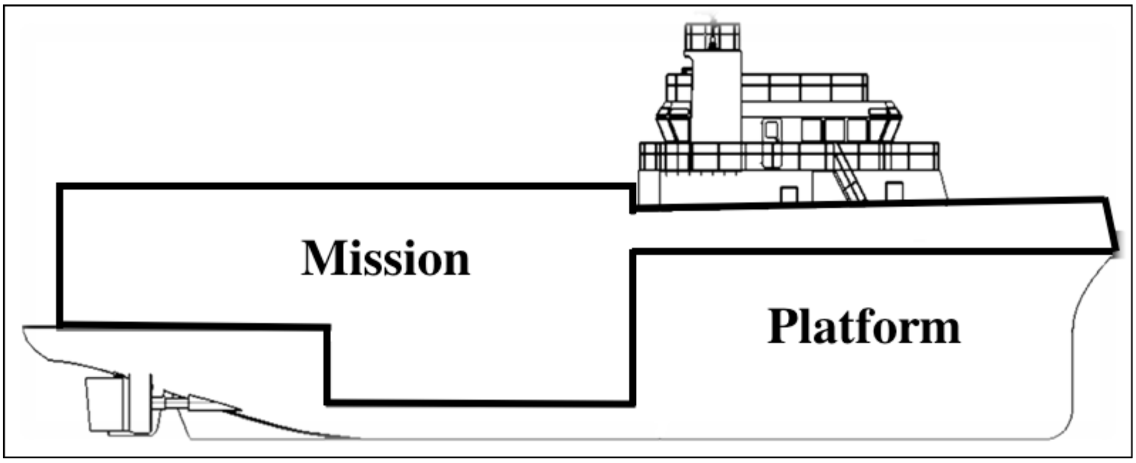


Figure 2-9 Ship platform concept

2.6.3 Modular approach in ship design

According to Kamrani and Nasr (2010), in order to increase the design accuracy and reuse of modules, modules should be defined, classified and analyzed first, which, is called as ‘decomposition analysis’. In this stage, relations between modules and sub-modules should be studied in details. Decomposition can make in different ways, which is mainly depending on the designers and purpose. The second phase of this methodology is to do product analysis, which requires to identify the components that could be produced and assembled separately and establish the interface. Relocating this knowledge in our library, in order to make a virtual arrangement in the final, we should be aware that:

- What is the reason for choosing this equipment rather than the other one?
- How to control the quantity of equipment?
- What if one equipment occupies the other’s location when both of them are suitable for one mission?

Associativity analysis between components and mission requirements has been proposed as a method to figure out how the modules interact with each other and how the modules would affect the performance (O. Chaves and H. Gaspar, 2015).

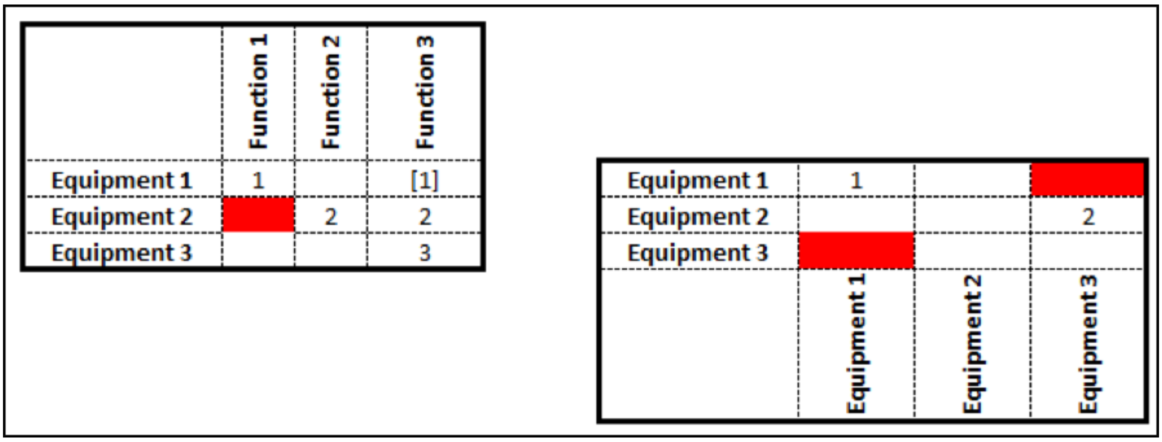
The Associative analysis of the mission (AAMIS) helps ship designers and other stakeholders to have a clear view about how one equipment or system is essential according to the mission requirement. AAMIS may reflect through numbers as equipment with higher values indicates that performance would be better once it is equipped on board.

2.6.4 Design structure matrix (DSM)

Steward (1998) pointed out that Design structure matrix can be used to manage the design of complex systems and highlight issues of information needs and requirements based on identify the dependencies between modules or between modules and functions. Also, DSM can be used to organize product development tasks to minimize unnecessary design iterations, also, it is able to increase the efficiency of the design process. A DSM consisting of parts or components can be defined as an architectural DSM, where the requirements, missions and equipment are placed either on the row or in the columns of the matrix and interactions between them are mapped (Hölttä – Otto, 2005). It depends on the designers to determine how the interactions happens to each other.

The DSM between equipment and function can help to select the useful equipment according to the requirement, however, the location for one selecting equipment may occupy another's, which means the two equipment cannot be installed simultaneously. Therefore, DSM between equipment should be analysed as well.

Figure 2-10 presents two DSM matrix, the left one shows the interaction between equipment and function while the right one describes the interactions between equipment. From the left DSM, we could know that equipment 1 is required to perform function 1 while equipment 2 can bring negative effect in run function 1 as shown in 'red' mark. Equipment 2 and 3 are needed to operate function 3 while equipment 1 is an option, which means the performance would become better once equipment 1 is installed. In the right DSM, we could obtain that equipment 1 and equipment 3 are conflict with each other, which means they cannot be equipped simultaneously, this may be caused by an overlap in the location. Last but not least, as we may notice that the relationship between equipment 1 and function 3 is described as [1] in the left DSM, it indicates that equipment 1 is not essential for function 3, whereas some spinoff function would be developed after the installation of equipment 1.



	Function 1	Function 2	Function 3
Equipment 1	1		[1]
Equipment 2	🟥	2	2
Equipment 3			3

Equipment 1	1		🟥
Equipment 2			2
Equipment 3	🟥		
	Equipment 1	Equipment 2	Equipment 3

Figure 2-10 Study case of DSM

In this study, the intelligent library will store equipment that could be installed on board, and it will be too much for DSM to figure out the interactions as there are quite a few kinds of potential equipment. However, when we analyse the equipment in details, we may find out that for some of the equipment such as capstans and guide pin, it is worthless to study the interaction with functionality and other main equipment because not only they are not big enough to cover other equipment's location, but they don't have a direct relation with mission requirement. For instance, if the mission requirement is 'anchor handling tug supply', the existence of capstan cannot help to run the function. Therefore, in our case, we will choose the main function-based equipment and analyse the interactions between them and functions.

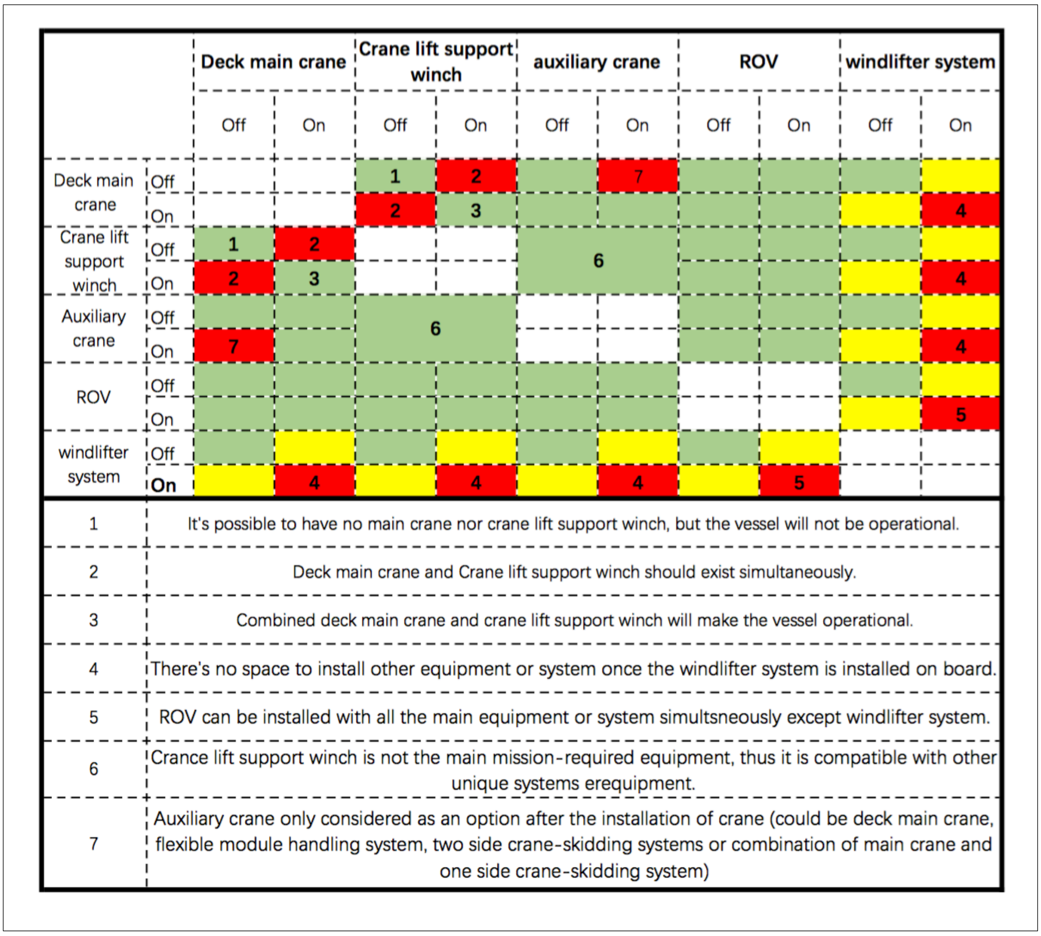
2.6.5 Compatibility matrix

The interactions between equipment are specific analysed and described through compatibility matrix, which is defined as the ability of two different equipment of different versions to interoperate. Possibilities of potential configuration arrangement solutions could be further studied with the help of compatibility matrix.

The equipment-compatibility matrix mainly contains the equipment that could either develop a new function for the vessel or improve the present performance. The primary objective of employing the equipment-compatibility matrix is because some equipment's locations may have overlaps with each other, also, it is pointless to install two different equipment that could develop the same function. Therefore, for the auxiliary equipment such as guide pin or stopper, their relations with main equipment would not be studied as they are common and have no collision with the main mission-related equipment.

In the matrix, equipment is listed both in the column and row, relationships between equipment are classified as compatible (marked as 'green') and incompatible (marked as 'red'). The relationships between two equipment marked as ‘yellow’ represent that they are compatible but restricted. Last but not least, some special statements regarding to the interactions between equipment would also presented through the compatibility matrix.

Figure 2-11 presents part of the whole compatibility matrix developed in the intelligent library, and it is consists of deck main crane, crane lift support winch, auxiliary crane, ROV and wind-lifter system. As we may notice that, wind-lifter system is in compatible with other equipment because there is no space to install the other equipment which works as a function-driver for the vessel, thus ‘red’ mark appears once the wind-lifter system and one of the other four equipment are ‘on’. Even though crane lift support winch doesn’t have a direct relation with the mission function, it works as a support machine to assist the deck main crane, and the dimension of it is not so small that can be ignored, therefore, the existence of crane lift support winch is viewed as a main function equipment. It is possible to have no main crane nor crane lift support winch, but as long as one of them is selected to be installed, the other should be applied as well because of stability issue. Auxiliary crane only considered as an option after the installation of crane (could be deck main crane, flexible module handling system, two side crane-skidding systems or combination of main crane and one side crane-skidding system).



		Deck main crane		**Crane lift support winch**		**auxiliary crane**		**ROV**		**windlifter system**	
		Off	On	Off	On	Off	On	Off	On	Off	On
Deck main crane	Off			🟩 1	🟥 2	🟩	🟥 7	🟩	🟩	🟩	🟨
	On			🟥 2	🟩 3	🟩	🟩	🟩	🟩	🟨	🟥 4
Crane lift support winch	Off	🟩 1	🟥 2			🟩 6	🟩	🟩	🟩	🟩	🟨
	On	🟥 2	🟩 3			🟩	🟩	🟩	🟩	🟨	🟥 4
Auxiliary crane	Off	🟩	🟩	🟩 6	🟩			🟩	🟩	🟩	🟨
	On	🟥 7	🟩	🟩	🟩			🟩	🟩	🟨	🟥 4
ROV	Off	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟨
	On	🟩	🟩	🟩	🟩	🟩	🟩			🟨	🟥 5
windlifter system	Off	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨		
	On	🟨	🟥 4	🟨	🟥 4	🟨	🟥 4	🟨	🟥 5		

1	It's possible to have no main crane nor crane lift support winch, but the vessel will not be operational.
2	Deck main crane and Crane lift support winch should exist simultaneously.
3	Combined deck main crane and crane lift support winch will make the vessel operational.
4	There's no space to install other equipment or system once the windlifter system is installed on board.
5	ROV can be installed with all the main equipment or system simultsneously except windlifter system.
6	Crance lift support winch is not the main mission-required equipment, thus it is compatible with other unique systems erequipment.
7	Auxiliary crane only considered as an option after the installation of crane (could be deck main crane, flexible module handling system, two side crane-skidding systems or combination of main crane and one side crane-skidding system)

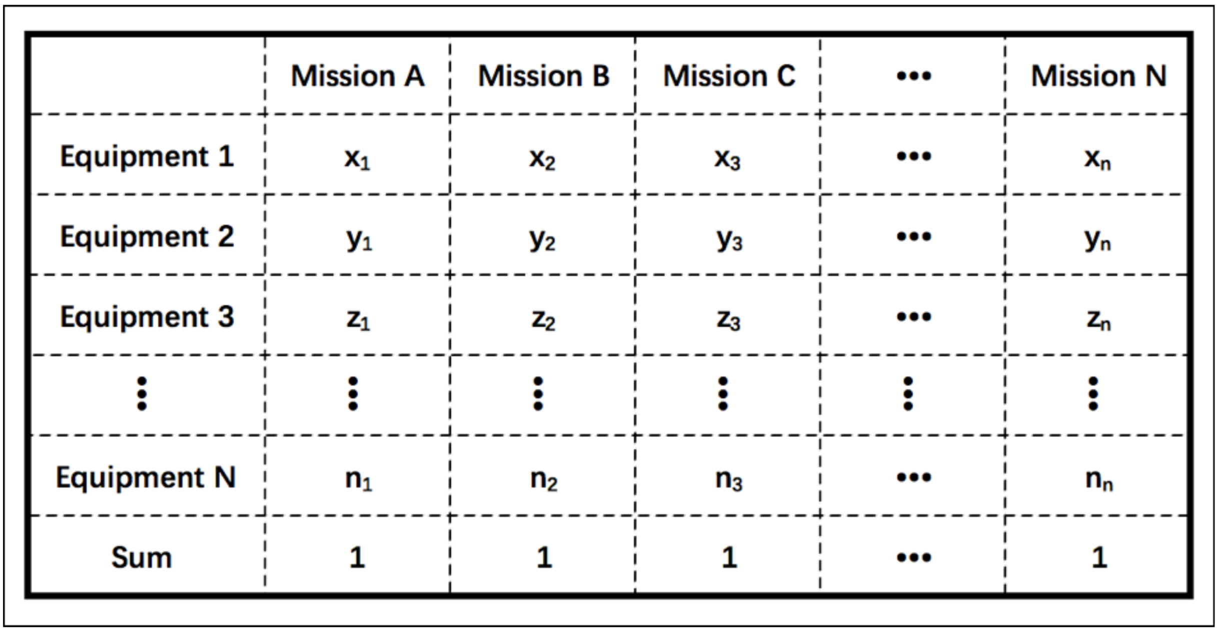
Figure 2-11 Part of equipment-compatibility matrix

Figure 2-11 shows how the layout of the equipment compatibility matrix, it is just a small part of the entire compatibility matrix and is only used for illustrative purposes.

2.6.6 Mission-equipment relationship management

The objective of assemblies is not just to make the equipment arrangement, but assemble the most suitable equipment for performing a given mission, and the presented design solution should also satisfy the mission requirement, this is the right vessel for the right mission (Gaspar, Brett, Erikstad, & Ross, 2015).

The main principle of the intelligent library is to follow requirements regarding to the functionality and performance settled by the customers, and further the suitable equipment would be organized and assembled and compared by in order to present the better arrangement. Mission-Modules Relationship Table (MMRT) is presented here and will be further applied in the study in order to make comparison for each potential arrangement solution (Chaves, Nickelsen, & Gaspar, 2015). This table specifically describes how essential one equipment is in order to operate the given mission by grading 'equivalent' credit. The credit varies from -1 to 1, for the equipment which is highly required according to the mission requirements, it would capture a high positive score, however, low negative score would be marked if the equipment is viewed as a useless tool or its action is counterproductive for achieving the wanted performance. For example, a new task requirement for the OSV is to perform the mission of 'offshore wind support', then obviously the 'wind-lift system' is the most suitable and essential equipment for this mission, which, would be graded an extremely high positive number such as 0.5. However, for the equipment such as deck 'main crane' and 'side crane-skidding system', they would both receive a low negative score not only because the existence of them cannot contribute to accomplish the given mission, but their location would occupy the position of 'wind-lift system' more or less. What is noteworthy is that for the equipment like 'ROV', which would neither conducive to perform the given mission nor affect the installation of 'wind-lift system', the credit is much more flexible, and it varies from designers to designers. Last but not least, the sum of credits for all equipment should be equal to 1 (Chaves et al., 2015).



	Mission A	Mission B	Mission C	•••	Mission N
Equipment 1	x_1	x_2	x_3	•••	x_n
Equipment 2	y_1	y_2	y_3	•••	y_n
Equipment 3	z_1	z_2	z_3	•••	z_n
⋮	⋮	⋮	⋮	⋮	⋮
Equipment N	n_1	n_2	n_3	•••	n_n
Sum	1	1	1	•••	1

Figure 2-12 Mission-Module Relationship Table (MMRT)

The design structure matrix exists in the selection of equipment aims to identify the general essential equipment among the numerous equipment-stored library. However, the MMRT gives a much more specific view regarding to the relationship between equipment and mission, which would contribute to figure out the better arrangement solution, and it can be identified as the 'cornerstone' in the phase of final decision, which is named as evaluation.

3 METHODOLOGY

3.1 Assumptions

A product can be decomposed in many different ways, and it depends on the predominant use to decide how to decompose (O. Chaves, 2015). Regarding the vessel as a huge product, decisions on which equipment are depending on the final use, cost and stakeholders, and the interactions inside the ship so complex that some essential assumptions have to be made in advance for developing the intelligent library without a hitch.

1) Information extracted from the mission requirements is clear enough for selecting the related equipment and the specific type.
2) There is a reason for locating the boundary of each equipment in each given place.
3) The equipment inside the library can develop a unique function once it’s installed on board whereas other equipment cannot.
4) There is no need to care about whether the arrangement is rational in mechanical or ship structural way in this study.
5) a vessel is usually assigned to do a single mission whereas it is much more common and competitive for ship designers to generate a ship design solution which makes the vessel achieve two or more mission functions simultaneously. In order to simplify the process and make it easy for the intelligent library to handle, we assume that each vessel would be assigned to a single mission function in the definition phase.
6) Equipment such as guide pin or capstan which neither occupy too much space on board nor has a direct relation with mission functionality is called auxiliary equipment. For simplification purpose, we assumed there is no relation between auxiliary equipment and mission function, also, and the location and quantities of the auxiliary equipment can be determined after the confirmation of main equipment. In this study, in order to simplify the process for intelligent library, auxiliary equipment would only consist of mooring system, bollard capstan, guide pin and stopper.
7) Before making the final arrangement, the performance level should be determined. Three different levels of performance are stated in the interface as: Breeze (standard edition) and storm (luxury edition). In common ship design process, the preference for each equipment vary from ship owners to ship owners, for instance, a ship owner may require an A-frame to be installed at a standard level which indicates the dimensions are small and would therefore occupy fewer spaces than the one at a luxury edition. However, ship owners may require a demanding deck main crane

which must be a luxury edition. Once these requirements are input into the library simultaneously, it will make the intelligent library hard to manage. Therefore, we hereby assumed that once the performance of equipment is required in a luxury edition, both equipment (main equipment and auxiliary equipment) and vessel deck would be designed at a maximum size (as can be seen in Table 3-1).

Edition	Platform	Dimensions for all main equipment and auxiliary equipment	Quantity of Auxiliary equipment			
			Mooring	Capstan	Guide pin	Stopper
Breeze	Small	Small	2	2	2	2
Storm	Big	Big	4	4	2	2

Table 3-1 Definition of performance requirement

3.2 *Intelligent algorithm*

3.2.1 Mass customization

Mass customization, a derivative of modularization, *it is the place in which an interaction with the customer adapts the products specifically to each user*. It is significant to accommodate the specific customer's requirement because large variations in product requires quite a few specific customized requirements. The 'system-based design' method has stated the importance of transforming the customer needs into a relatively detailed definition of specific functional requirements (Levander, 2006).

The establish of custom interface in a mass customization affects the product configuration system. As described by Hvam et al. (2008), who also pointed that it is important to assign a team to design a configuration system in order to satisfy as many requirements as possible and not just focus on one.

3.2.2 Interface definition

Interface is defined as the place or area at which different things meet and communicate with or affect each other. In our case, the interface is the place where mission requirements can be specific listed and input by ship designers, precondition should be confirmed here before starting the intelligent library.

In this case, type of mission should be determined first in order to filter the proper equipment from the library as the library is functionality-based. Product platform (vessel platform) will be constructed according to the length and beam of the vessel. Performance will be further confirmed for choosing the specific size of equipment. only one option can be determined inside these four parts (‘mission’, ’length range’, ’beam range’, ’performance requirement’)

Normally, the settings of offshore vessel dimensions are flexible but they do have limitations. For instance, if the length of ship is inside the range from 50m-70m, then the beam would vary from 10m-20m, or it would even in the range of 20m-25m. however, it is unconscionable to define the beam of a vessel in the range of 25m-30m while it’s length is in the range of 50m-70m. The same also applies to the vessel, of which the length is from 90m-110m, the beam should not be defined too small. However, for the vessel, which has the length in the range from 70m-90m, the definition of beam is flexible.

In order to make virtual arrangements based on the alternative arrangement-solutions, a web-based APP will be employed and do the simulations, equipment would be replaced by blocks and will be further configured on a virtual deck with the help of the APP tool according to the different kinds of arrangements, which will be studied in the later chapters. As a matter of fact, before making the virtual arrangements, the cargo deck (product platform) should be defined first. The dimension of product platform not only depends on the dimension of vessel, but it is also affected by the performance requirements. As there are three kinds of performance edition, once combined numerous kinds definitions of vessel dimension, various specific types of product platforms should be predefined, which, is too much for the intelligent library to handle. Therefore, in order to simplify the procedure, we hereby define that for the vessel which has the small-length vessel (50m-70m), the range of beam can only from 10m-20m. for the medium-length vessel (70m-90m), the range of beam can only from 20m-25m, and for the large-length vessel (90m-110m), the range of beam can only from 25m-30m. In this case, there will be 9 kinds of product platforms altogether.

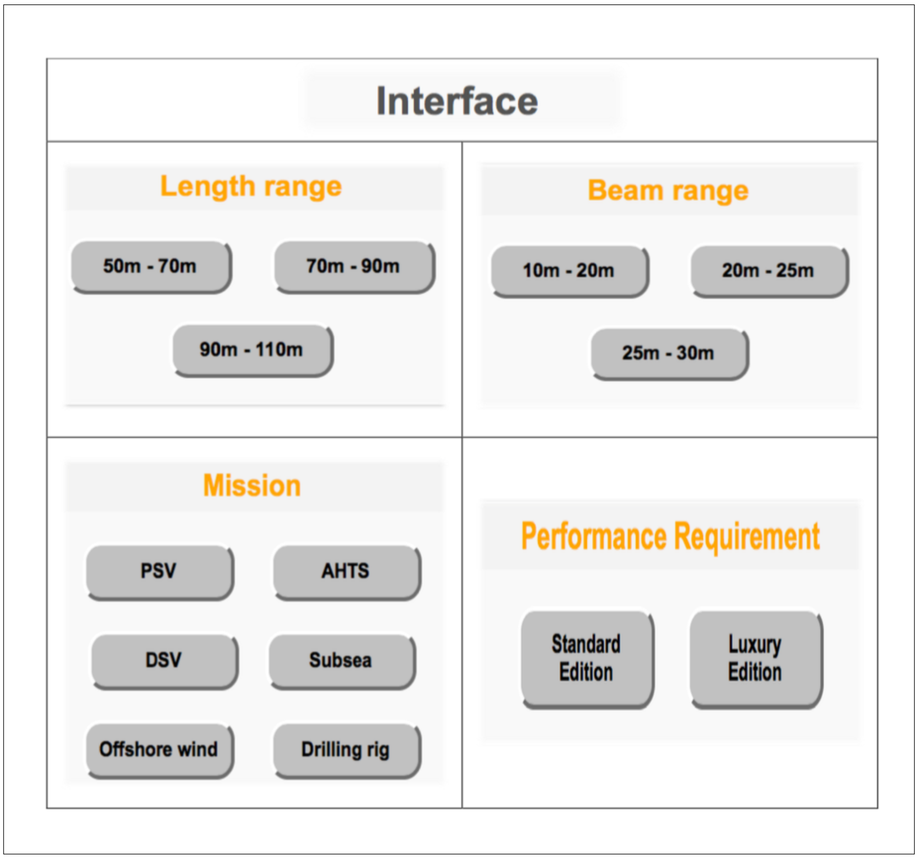


Figure 3-1 Interface definition of Intelligent Library

3.2.3 Specific process principle

A specific design should start from the mission specified for the vessel (Erikstad & Levander, 2012). Refining the function-related requirements from the numerous mission statements, the intelligent library would start the design procedure as ‘Capability definition—Balance control—Arrangement-making—Evaluation’. This approach skilfully embeds the spiral system into the whole design procedure (see as Figure 3-2), which can not only reduce the loops needed to generate the mission-satisfied arrangement solutions, but it could also help to identify the better arrangement design.

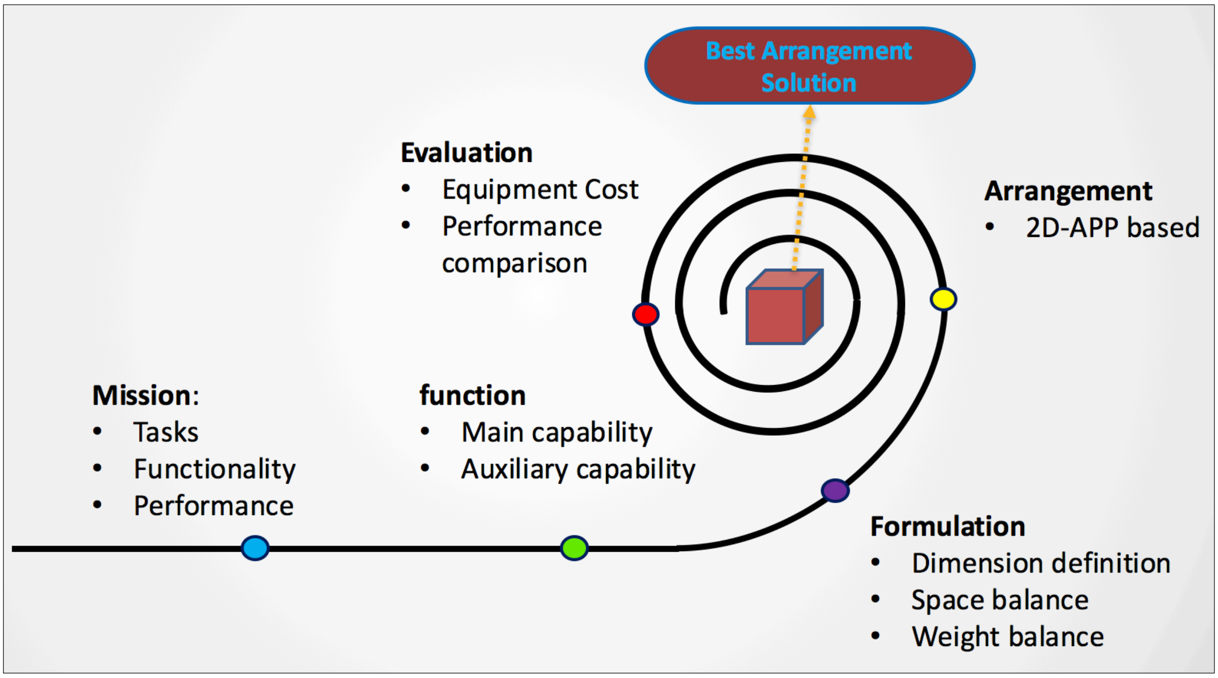


Figure 3-2 Spiral Design Process

The general spiral design process can be described as following:

- Mission

  specific mission requirement's statements regarding to the functionality, task, performance, operating area, endurance. Also, the classification society and rules would also be included in this announcement presented by the ship owners or operators.
- Function

  Extracting all functionality-related information for confirming the main and auxiliary capability, which can be further used to define the capacity and weight of the mission-related equipment, with which the dimension of product platform could be designed by then.
- Formulation

  According to the endurance of the vessel in terms of the capacity and weight, the specific quality and quantity of equipment could be further identified after the balance control regarding to the space and weight.
- Arrangement-making

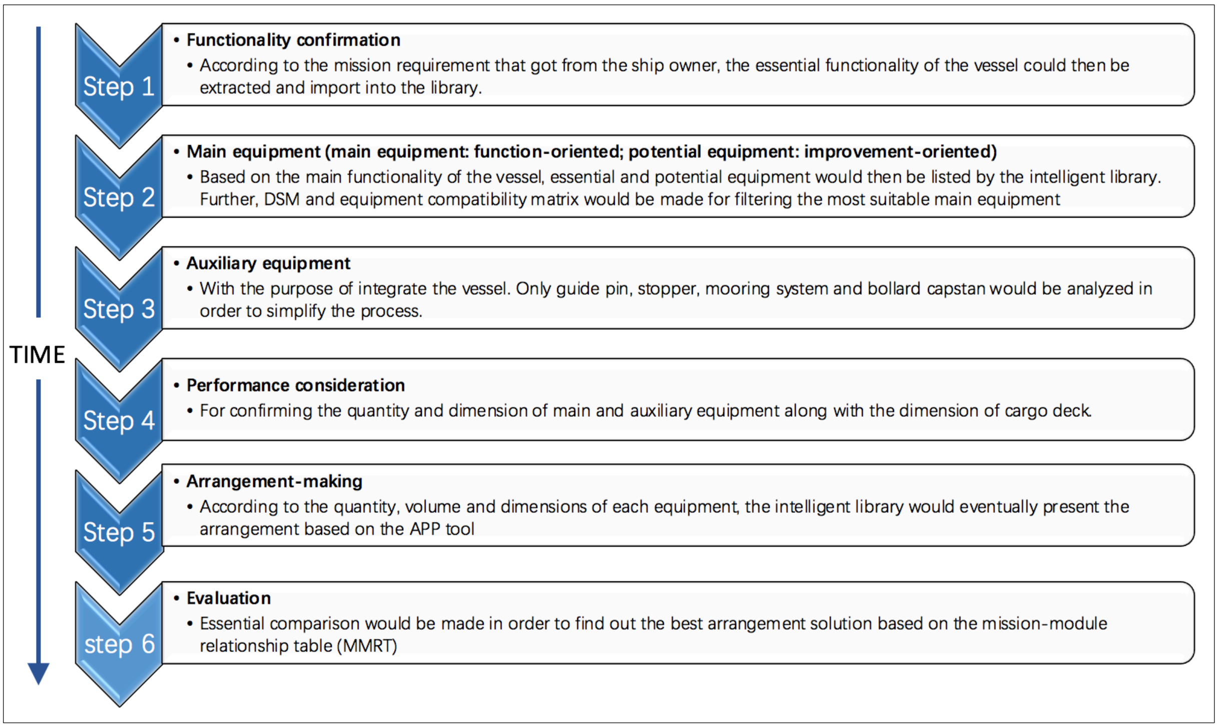
  Arrangement-making design solutions generated after the three steps above may vary from each other. The corresponding virtual 2D arrangements would be made in order to give both ship designers and customers a direct view.

- Evaluation

  In order to seeking out the better arrangement design among the alternative choices, the performance credit of each design solution would be specific calculated respectively, which would also be mentioned and described in the later chapter.

- Better-arrangement solution

  A 3D arrangement would be presented according to the 2D-arrangement through the Siemens-NX by employing the blocks to replace equipment as well, which aims to give ship designers and other stakeholders a straight view about the final arrangement.



- **Functionality confirmation**
  - According to the mission requirement that got from the ship owner, the essential functionality of the vessel could then be extracted and import into the library.
- **Main equipment (main equipment: function-oriented; potential equipment: improvement-oriented)**
  - Based on the main functionality of the vessel, essential and potential equipment would then be listed by the intelligent library. Further, DSM and equipment compatibility matrix would be made for filtering the most suitable main equipment
- **Auxiliary equipment**
  - With the purpose of integrate the vessel. Only guide pin, stopper, mooring system and bollard capstan would be analyzed in order to simplify the process.
- **Performance consideration**
  - For confirming the quantity and dimension of main and auxiliary equipment along with the dimension of cargo deck
- **Arrangement-making**
  - According to the quantity, volume and dimensions of each equipment, the intelligent library would eventually present the arrangement based on the APP tool
- **Evaluation**
  - Essential comparison would be made in order to find out the best arrangement solution based on the mission-module relationship table (MMRT)

Figure 3-3 Step-By-Step Process Algorithm

Figure 3-3 describes the specific description of how the intelligent library works from receiving the mission requirements till making the corresponding arrangement, including the specific methodology applied in each steps.

Step 1: Functionality confirmation

Recalling one of the assumptions, each vessel would only be assigned to a single mission function, therefore the mission functionality and main dimensions would be defined here as the basic condition of the final vessel equipment-arrangement.

Step 2: Main equipment listing

The main equipment listing phase is based on the refining the characteristics of the vessel, according to which the product architecture and design structure matrix would be presented in order to reveal the corresponding equipment, the equipment studied here is called main equipment such as A-Frame, deck main crane and etc. Interactions between equipment would be further analysed throughout the compatibility matrix before determine the equipment to be installed due to the overlap issue or stability issue. Auxiliary equipment such as capstan and normal winch would not be analysed here because they do not have a direct relation with the mission functionality, and the installation of auxiliary equipment would not affect either the boundary of main equipment location or the vessel stability requirement.

Step 3: Auxiliary equipment appearance

Once the main equipment is confirmed in step 2, the location and quantity of auxiliary equipment would then be analysed in order to make the platform arrangement more integrated. In this study, the auxiliary equipment refers to the mooring system and bollard capstan, which is assumed for simplification purpose.

Step 4: Performance consideration

The objective of the performance consideration phase is to determine the main dimension both for the main equipment and auxiliary equipment, also, the dimension of the deck which is replaced by a platform would also be confirmed along with the quantity and location of auxiliary equipment. Different performance would assemble the equipment in different ways, thus the decisions has to be made between the two different levels: breeze (standard edition) and storm (luxury edition).

Step 5: Arrangement-making

Once all essential choices are determined after all four steps, a virtual arrangement prototype would be produced by the intelligent library in 2D. The 2D arrangement is based on employing a web-based app which has been made for handling ship design layout during conceptual phase. Replacing equipment as blocks stored inside the data-based library (.csv file), the app could read the blocks and plot them into a grid. Positions, attributes, neighbours and connections could be further analysed and evaluated. Besides, the reason to employ the web-based APP to make a virtual arrangement is because the availability of 3D model in early stage would influence the choice of design process, and it might also lock the ship designers into their original assumptions.

In fact, the employment of the APP is to simulate the product platform, which is hereby the cargo deck. The objective of intelligent library is to generate a relatively better equipment arrangement-making design solution according to the various mission requirements, and the location of all equipment is the cargo deck. Apart from the equipment, the various mission requirements affect the dimension of product platform as well. Therefore, specifications have to be formulated under the circumstances of diverse related factors. In order to simplify the whole working procedure inside the intelligent library, we hereby the ship length and ship beam are corresponded to each other, in other word, if the ship length is from 50m to 70m, the ship beam could only be from 10m to 20m, and this is the small vessel size, the same applies to the medium vessel size (length:70m-90m, beam: 20m-25m) and big size (length:90m-110m, beam: 25m-30m). Three different types of Length-width ratio of cargo deck are set for each size of vessel according to three different kinds of performance requirement, which, can be seen in Table 3-2.

Ship length	**Ship beam**	**Length-width ratio of product platform**	
		Standard edition	**Luxury edition**
50m – 70m	**10m – 20m**	**52 : 16**	**66 : 20**
70m – 90m	**20m – 25m**	**70 : 21**	**82 : 25**
90m – 110m	**25m – 30m**	**92 : 27**	**98 : 30**

Table 3-2 Dimension set for product platform

Step 6: Evaluation

The MMRT is supposed to apply here in order to evaluate how important each equipment is for the given mission, with which the performance credit of each arrangement-making design would be further calculated. By comparing the data computed, the better arrangement solution is then able to be presented both in 2D and 3D, which is supposed to be included in one more step. Besides, the reason of make the 3D virtual arrangement after this step is because of the complexity of 3D virtual arrangement-making method, once too much arrangement design solutions appear before step 5, it would take a lot of time to generate the corresponding ‘after model’, which runs contrary to the philosophy of the ‘intelligent library’.

3.3 Case attempt

In order to study the feasibility of the process algorithm of the intelligent library, we would make an attempt in a simple case: platform supply vessel (PSV). A virtual equipment arrangement would be finally presented by employing the blocks which used to replace the equipment, the whole arrangement procedure would follow the process described before.

- **Step 1 Functionality confirmation**

As can be seen from the specific selection inside the interface (see in Figure 3-4), PSV is the main function for the vessel to operate while both the length and beam are the biggest size. standard edition ('breeze') is selected as the performance requirement, which indicates the specific information as shown in Table 3-3.

Edition	Platform	Dimensions for all main equipment and auxiliary equipment	Quantity of Auxiliary equipment			
			Mooring	Capstan	Guide pin	Stopper
Breeze	small	Big	2	2	2	2

Table 3-3 Definition luxury performance

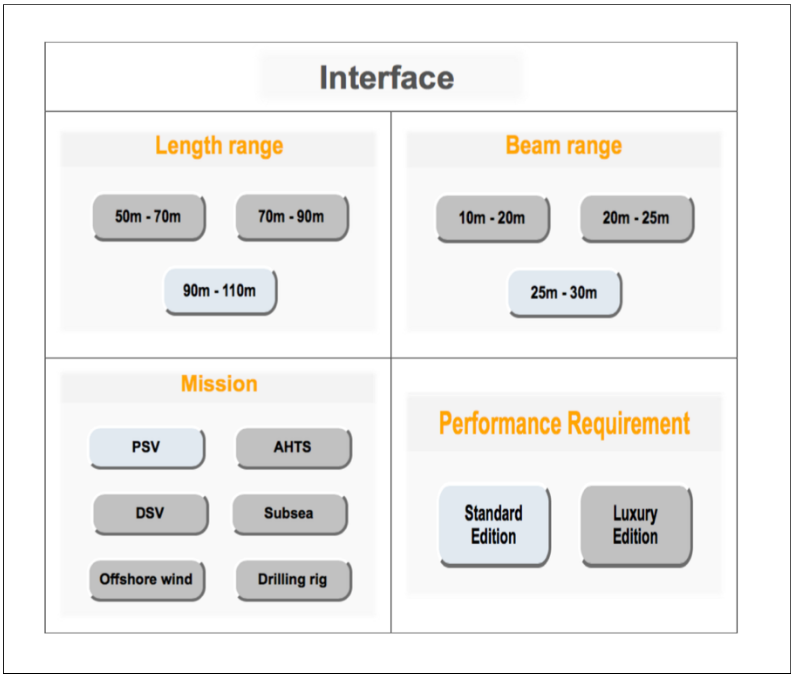
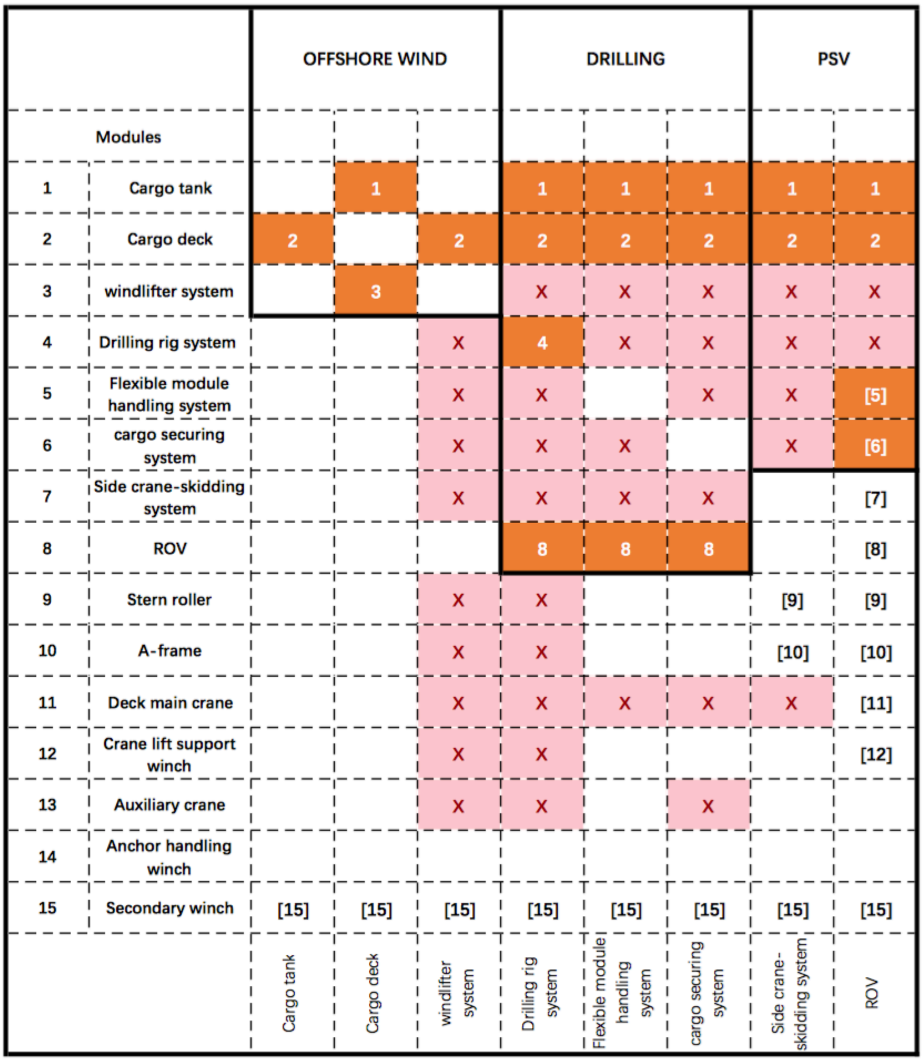


Figure 3-4 Interface set in small case

- Step 2 Main equipment listing

PSVs are specially designed for providing transportation and logistics support for the supplies and equipment used on oil and gas platform, and it doesn't have accurate requirements about the necessary equipment that should be installed on board, thus the section of equipment varies from designers to designers. Unlike anchor handling tug supply vessel and wind-lifter support vessel, the capability of platform supply vessel is much more flexible, which makes the function hierarchy hard to describe. Instead, design structure matrix (DSM) would be applied for analysing whether the main equipment stored in the library is suitable for performing the main mission (platform supply).

DSM is mainly used for study the interactions between equipment and functions. Figure 3-5 is intercepted from the whole DSM which can be found in the Appendix II – Design Structure Matrix, and it is used for analyse the small case only.



		OFFSHORE WIND			DRILLING			PSV	
Modules									
1	Cargo tank		1		1	1	1	1	1
2	Cargo deck	2		2	2	2	2	2	2
3	windlifter system		3		X	X	X	X	X
4	Drilling rig system			X	4	X	X	X	X
5	Flexible module handling system			X	X		X	X	[5]
6	cargo securing system			X	X	X		X	[6]
7	Side crane-skidding system			X	X	X	X		[7]
8	ROV				8	8	8		[8]
9	Stern roller			X	X			[9]	[9]
10	A-frame			X	X			[10]	[10]
11	Deck main crane			X	X	X	X	X	[11]
12	Crane lift support winch			X	X				[12]
13	Auxiliary crane			X	X		X		
14	Anchor handling winch								
15	Secondary winch	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]
		Cargo tank	Cargo deck	windlifter system	Drilling rig system	Flexible module handling system	cargo securing system	Side crane-skidding system	ROV

Figure 3-5 DSM of small case

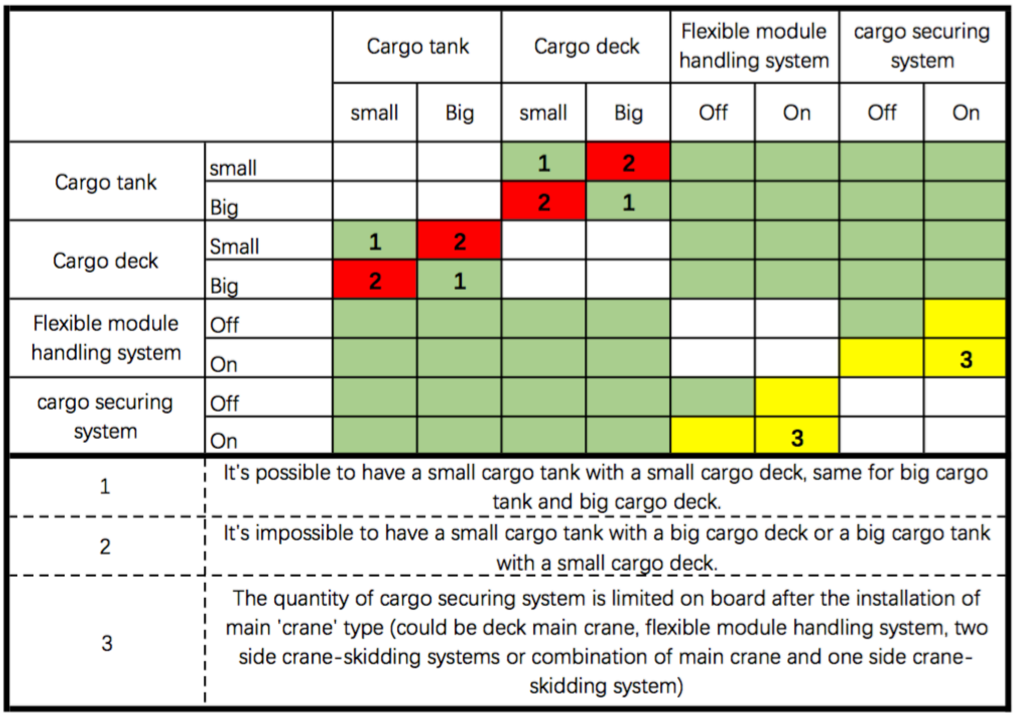
The DSM shows that cargo tank and cargo deck are essential for PSV, drilling and Offshore wind. These two units are in fact not belong to equipment, which, should be classified into hull structure. However, as all types of OSV require the cargo deck which is used as a platform for further install the equipment inside, they are still viewed as part of the equipment modules.

The interactions between equipment and function are classified in three types: 'required' (orange colour marked with number), 'optional' (orange colour market with parenthesized number) and 'prohibited'. The equipment marked as 'required' indicates that it is essential to install that equipment in order to operate the given mission such as the relations between 'Drilling rig system' and 'Drilling mission'. If the equipment is marked as 'optional', it means that this equipment is improvement-oriented, which means that the equipment can help to improve the mission performance even though it is not criteria for the mission, therefore, whether to select the ‘optional’ equipment depends on the ship designers and specific performance requirements. Besides, there’s also a kind of relationship which describes only with uncoloured parenthesized number, it means that the equipment cannot either develop a function which is required for the mission or help to improve the mission performance, however, with the installation of that equipment, the vessel may develop some spinoff functions. For instance, the relation between ROV and PSV is described with uncoloured parenthesized number, this is because the installation of ROV cannot help to accomplish the main mission whereas the existence of it is beneficial for the vessel to perform ROV support mission. The relations that marked as ‘prohibited’ between equipment and function, there are conflict between each other, like deck main crane and ‘offshore wind’ mission, wind-lifter system has to be installed in order to perform that mission, which cannot be replaced by any other equipment or system. However, once deck main crane is installed on board, it would occupy the location of wind-lifter system, without which would fail the mission.

As ‘standard edition’ is determined as the performance requirement in the case, which indicates that only the required and optional equipment would be selected and applied into the arrangement according to the DSM. Therefore, combining with the DSM of PSV, we would then choose the flexible module handling system, cargo securing system as the main equipment, along with the cargo deck and cargo tank.

In this phase, the compatibility matrix would also be applied after the analysis of DSM in order to study the specific interactions between choosing equipment.

From the compatibility matrix, we could refine that flexible module handling system and cargo securing system are compatible with each other in general whereas there do have some limitations. Once both the flexible handling system and cargo securing system are determined to be installed, only two cargo securing system could be installed in total. However, if only cargo securing system is decided to be employed on board, four cargo securing system could be equipped simultaneously.



		Cargo tank		Cargo deck		Flexible module handling system		cargo securing system	
		small	Big	small	Big	Off	On	Off	On
Cargo tank	small			🟩 1	🟥 2	🟩	🟩	🟩	🟩
	Big			🟥 2	🟩 1	🟩	🟩	🟩	🟩
Cargo deck	Small	🟩 1	🟥 2			🟩	🟩	🟩	🟩
	Big	🟥 2	🟩 1			🟩	🟩	🟩	🟩
Flexible module handling system	Off	🟩	🟩	🟩	🟩			🟩	🟨
	On	🟩	🟩	🟩	🟩			🟨	🟨 3
cargo securing system	Off	🟩	🟩	🟩	🟩	🟩	🟨		
	On	🟩	🟩	🟩	🟩	🟨	🟨 3		

1	It's possible to have a small cargo tank with a small cargo deck, same for big cargo tank and big cargo deck.
2	It's impossible to have a small cargo tank with a big cargo deck or a big cargo tank with a small cargo deck.
3	The quantity of cargo securing system is limited on board after the installation of main 'crane' type (could be deck main crane, flexible module handling system, two side crane-skidding systems or combination of main crane and one side crane-skidding system)

Figure 3-6 Equipment compatibility matrix illustration

- Step 3 Auxiliary equipment appearance

As the assumptions made, vessel designed here is assumed to operate a single mission at a time, therefore, no more main equipment would be analysed. For the decision regarding to the auxiliary equipment, as the performance requirement is 'standard edition', the quantity of mooring system, bollard capstan, guide pin and stopper are stated in the 'functionality confirmation' phase.

- Step 4 Performance consideration

As the performance requirement is 'standard edition', which indicates that dimensions for both main equipment and auxiliary equipment would be in a small-size.

Before making the virtual arrangement, the alternative equipment arrangement design solutions should be summarized. As the flexible module handling system and cargo securing system are the alternative main equipment, and the two equipment are compatible with each other, thus there are mainly four combinations:

A. Flexible module handling system (quantity: one) only;

B. Cargo securing system (quantity: four) only;

C. Combined flexible module handling system (quantity: one) and cargo securing system (quantity: two);

D. None.

Both flexible module handling system and cargo securing system are equipment which can help to improve the mission performance. Therefore, solution A and D would be excluded.

Combining the auxiliary equipment, the alternative equipment combinations can be summarized as following:

> **Solution 1**: cargo securing system (quantity: four), guide pin (quantity: two), capstan (quantity: two), mooring system (quantity: two); stopper (quantity: two).
>
> **Solution 2**: flexible module handling system (quantity: one), cargo securing system (quantity: two), guide pin (quantity: two), capstan (quantity: two), mooring system (quantity: two); stopper (quantity: two).

- Step 5 Arrangement making

The 2D arrangement is made by the employment of a ship design tool—a web-based APP, which is developed by H. M Gaspar (2015). This tool demonstrates that it is possible to develop a web-based app for making ship design layout in a short time during the conceptual phase (H. M Gaspar, 2015).

Recalling the process regarding to the selection of main equipment, it depends on the ship designers to decide whether to install flexible module handling system or cargo security system. Combining one of these two main equipment with stern roller, A-frame and auxiliary equipment (mooring system and bollard capstan), there would be 5 different kinds of equipment which is going to be installed on board in total. In order to give ship designers and other stakeholders a direct view about how the arrangement with two different main equipment (flexible module handling system and cargo security system) would distinct from each other, we would make the arrangement for both the two arrangement design solution.

Solution 1

In the web-based app, each block is viewed as a single unit square, the cargo deck is composed of a large amount of blocks, and the equipment's requirement regarding to the amounts of blocks differs from each other. According to the selection made in the the first step, the length and beam of OSV is in a big size, as a result, more blocks are demanded in order to form the big cargo deck. Figure 3-7 shows the arrangement design solution which employs the cargo security system as the main equipment, the platform (cargo deck) contains 2940 block units. As definition of the length-width ratio of product platform in the earlier phase, the length of the deck is 92 units while the beam is 27 units, and each of them is belong to the 'big-size' (length defines the range from 90m to 110m as 'big'-size while beam defines the range from 20m to 30m as 'big-size').

The arrangement made by web-based APP can be seen as a top view of vessel, inside which the location of ship bridge is fixed and cannot have any overlap with any other equipment. The first column represents the stern of the vessel while the 98th column is the bow.

According to the performance requirements, 'standard edition' is chosen to be applied, which indicates that there will be two mooring systems, two capstans, two guide pins and two stoppers to work as auxiliary equipment on board. Besides, the specifications for each equipment is in a 'small-size', the dimensions and locations are fixed for simplification purpose.

The dimensions of each equipment are described by the width and height while the location of each equipment or system is presented by the combination of those four dimensions (width, height, row and column). Location for each unit is described as [A, B], inside which A indicates the row number while B shows the column number (specific description for each equipment can be seen in Figure 3-8). Starting from the given row and column, adding required height units and width units on the basic of row and column respectively, the location of each equipment would be further confirmed. For instance, the starting point of mooring system 1 is [0,7], and both of the width and height of mooring system 1 are 4 units respectively, combining the dimensions with the starting point, we could further know the boundary of the mooring system 1 is: [0,7], [0,11], [4,7] and [4,11]. The rectangle block surrounded by the four boundary points describes the how the stern roller would locate in 2D arrangement.

The APP reads the blocks from a database (see as Figure 3-8), which can be further plotted into grid. Boundaries between equipment can be seen clearly from this virtual 2D arrangement.

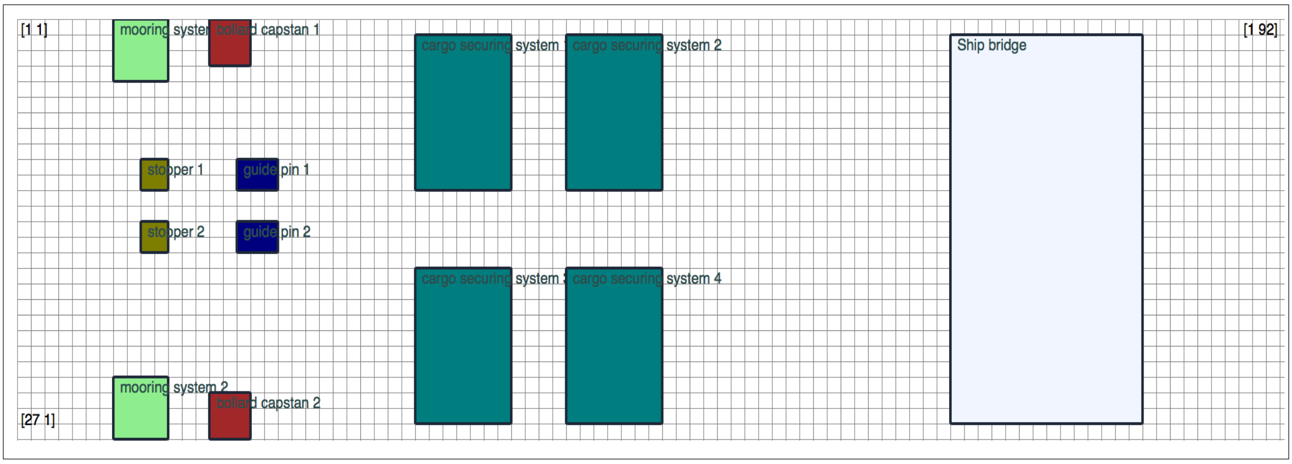
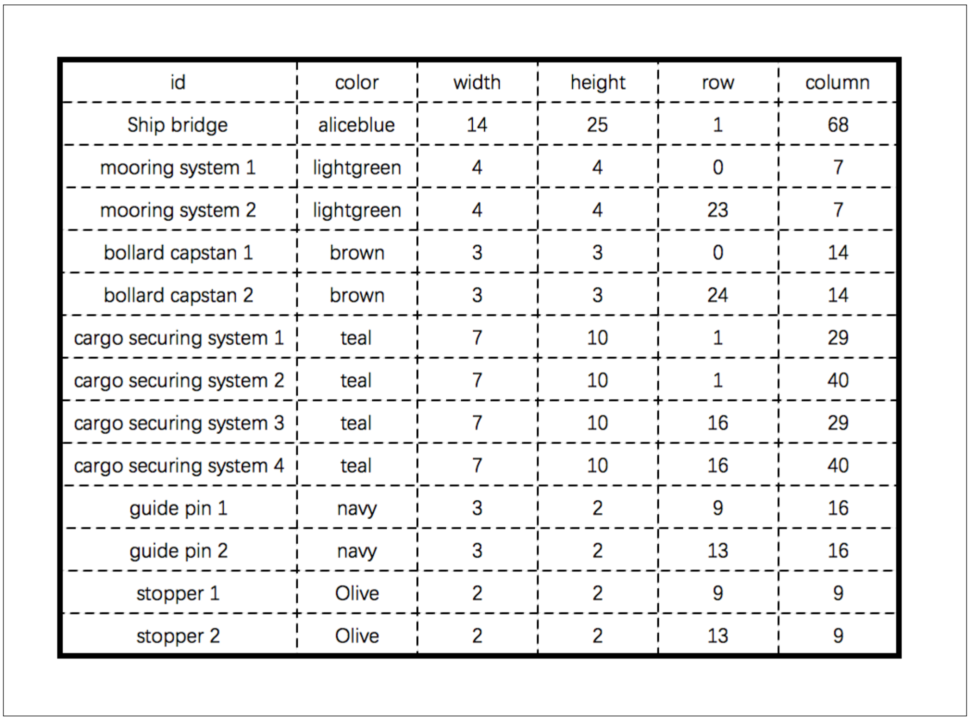


Figure 3-7 Arrangement solution 1 of small case



id	color	width	height	row	column
Ship bridge	aliceblue	14	25	1	68
mooring system 1	lightgreen	4	4	0	7
mooring system 2	lightgreen	4	4	23	7
bollard capstan 1	brown	3	3	0	14
bollard capstan 2	brown	3	3	24	14
cargo securing system 1	teal	7	10	1	29
cargo securing system 2	teal	7	10	1	40
cargo securing system 3	teal	7	10	16	29
cargo securing system 4	teal	7	10	16	40
guide pin 1	navy	3	2	9	16
guide pin 2	navy	3	2	13	16
stopper 1	Olive	2	2	9	9
stopper 2	Olive	2	2	13	9

Figure 3-8 Equipment's blocks definition for employing the web-based APP

Solution 2

Figure 3-9 shows the arrangement with the employment of both flexible module handling system and cargo securing system. The methods of applying the arrangement into the web data-based APP is the same as solution 1.

As we can see from the virtual arrangement of soliton 2, the flexible module handling system occupied the locations of two of the cargo securing system in solution 1, and that is why only two cargo securing system can be installed in this design. Besides, the space between the flexible module handling system and ship bridge is used to deploy the equipment which is neither essential or optional for the mission whereas it may bring spinoff functions for the mission once it is installed, and those kinds of equipment would only be considered under the luxury edition, and even that type of equipment would not be installed in the standard edition, the space cannot be used to adjust the location of installed equipment. Moreover, Location of each equipment is fixed in every edition of product platform.

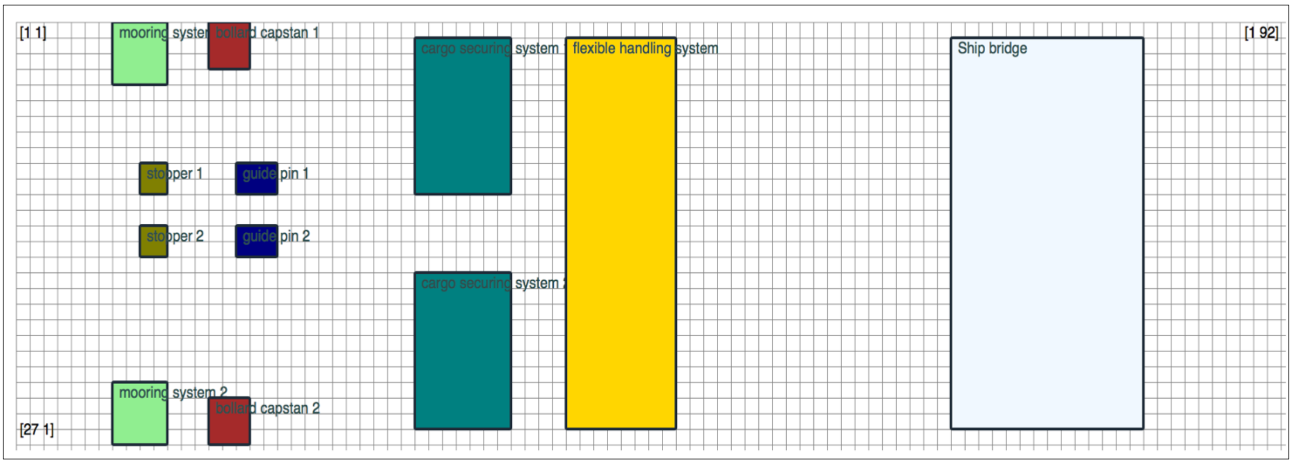
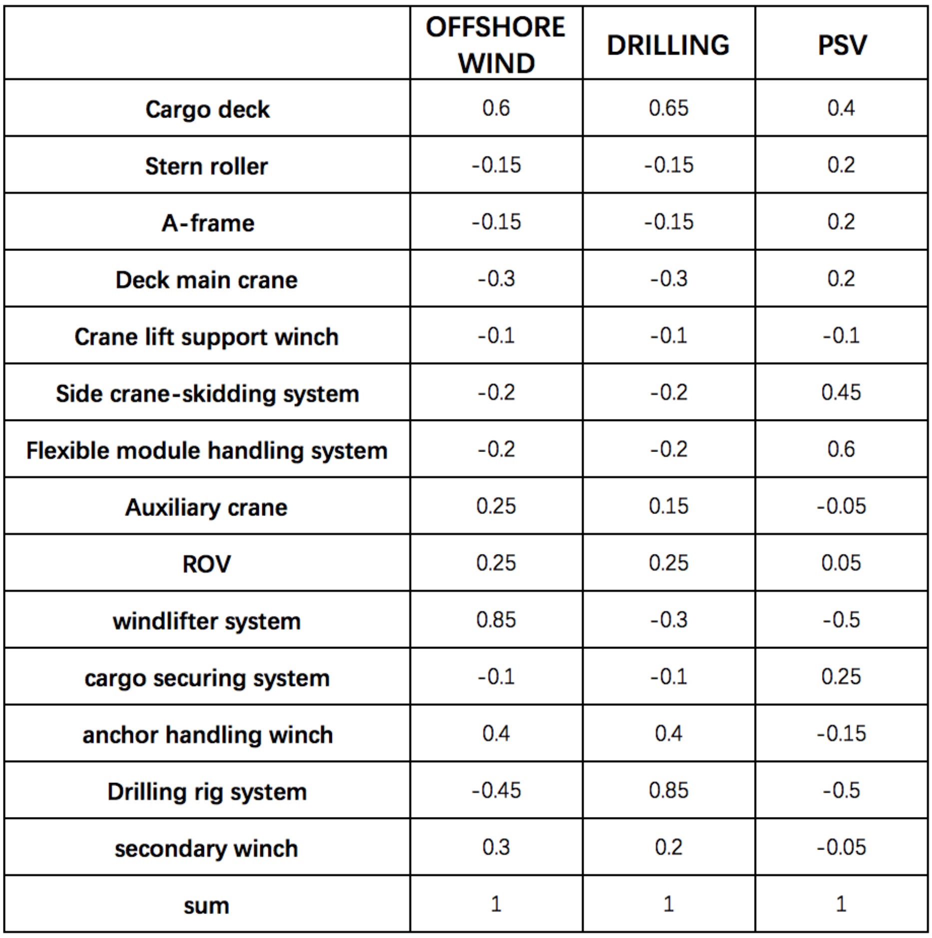


Figure 3-9 Arrangement solution 2 of small case

- Step 6 Evaluation

The comparison of equipment-arrangement design solutions is mainly based on the MMRT, which can be seen in Figure 3-10. As standard edition is selected to be the performance requirement, which indicates that all the alternative design solutions would not generate any spinoff functions, therefore the key to compare these two solutions is to observe how they would interact with the platform supply mission. On the basis of MMRT, it would be summarized that both the two main equipment (flexible module handling system and cargo securing system) have a positive effect in performing the PSV mission, whereas solution 2 which install flexible module handling system and cargo securing system simultaneously could better operate the mission.



	OFFSHORE WIND	DRILLING	PSV
Cargo deck	0.6	0.65	0.4
Stern roller	-0.15	-0.15	0.2
A-frame	-0.15	-0.15	0.2
Deck main crane	-0.3	-0.3	0.2
Crane lift support winch	-0.1	-0.1	-0.1
Side crane-skidding system	-0.2	-0.2	0.45
Flexible module handling system	-0.2	-0.2	0.6
Auxiliary crane	0.25	0.15	-0.05
ROV	0.25	0.25	0.05
windlifter system	0.85	-0.3	-0.5
cargo securing system	-0.1	-0.1	0.25
anchor handling winch	0.4	0.4	-0.15
Drilling rig system	-0.45	0.85	-0.5
secondary winch	0.3	0.2	-0.05
sum	1	1	1

Figure 3-10 MMRT of PSV

4 CASE STUDY

In the following chapter, we are going to apply this intelligent library in a more complex case, which is hereby called ‘big case’. The objective of this big application is to give a much more specific view about what the whole process would looks like, how to use the the methodology in a proper way, how to do the evaluation regarding to numerous alternative arrangement solution and what the final arrangement would look like in 3D.

As one of the most important type of OSV vessel, AHTS vessel has its characteristic design methodology. Normally, AHTS performs the role of assisting offshore installation with the anchor handling operation (Wennersberg, 2009). The primary mission of the big OSV vessel case is anchor handling tug supply, and the vessel is intended to perform several potential roles simultaneously by equipping a set of alternative versatile equipment. By comparing these different kinds of alternative arrangement-solutions, a better design method could be stand out in order to satisfy the customer’s requirements as better as possible.

4.1 Outline of Case description

AHTS has three main common types: the North European Anchor Handling Tug, the American Anchor Handling Tug and the Anchor Handling Tug and Supply Vessel (Michael Hancox, 1992). The specific characteristics of these three types of AHTS would not described, instead, the feature they have in common would be studied here in order to have a better understanding about how to make arrangement in a proper way.

In general, *placing the platform anchors in the correct position* is the main task for AHTS, and they are also used to supply operation by relocating and recovering anchors (Erikstad & Levander, 2012). This vessel is always designed along with large deck in the aft, which allows anchors and other equipment to be landed and dragged about the deck without any damage to the ship. In order to do the towing operation, AHTS is usually equipped with a stern roller or bar which provides the rotation hub to swing to the required position. In order to perform the primary and auxiliary mission, anchor handling winch, guide pin and cargo handling crane are usually defined to be installed in AHTS, and they are usually located in the forward section of the aft deck.

Figure 4-1 General deck equipment layout of AHTS (Ulstein)

4.2 Product architecture

As ship owners or operators intend to require the vessel to achieve two or more mission requirements simultaneously, a set of corresponding mission-related equipment should be analysed in order to assist the ship to perform various roles, which, would make the final equipment list huge. Following comes some short description of the function of some alternative equipment.

Guide pin

A vessel may be equipped with several work wires, which could not only be used to place anchors, but they can also assist to do the towing operation. The guide pins could hold the position of the vessel by control the work wires during the operation in the seaway.

Wire stopper

The stopper usually appears along with the guide pin, and works like a back-up solution, in other word, sometimes the vessel keeps on swaying under the control of guide pin, by having the wire stopper behind the guide pin, the position of vessel could be controlled stationary. Besides, the installation of stopper is good for crew safety during some harsh working condition.

Stern roller

The wires-pulling operating in the stern can cause high friction, which would damage the vessel. By having the stern roller could help reduce the resistance in the aft ship. Towing operation should be assisted with stern roller (Michael Hancox, 1992).

A-frame

A-frame is designed with a lifting capacity from 10T to 250T aims to help to do the plough handling and subsea handling.

Anchor handling winch

AHTS winches are usually consist of double or triple drums, and all drums are connected to one system. equipping this kind of winch on board could help to realize local control for maintenance and remote control for operation.

The establish of the product architecture is based on the equipment and the unique function they could provide.

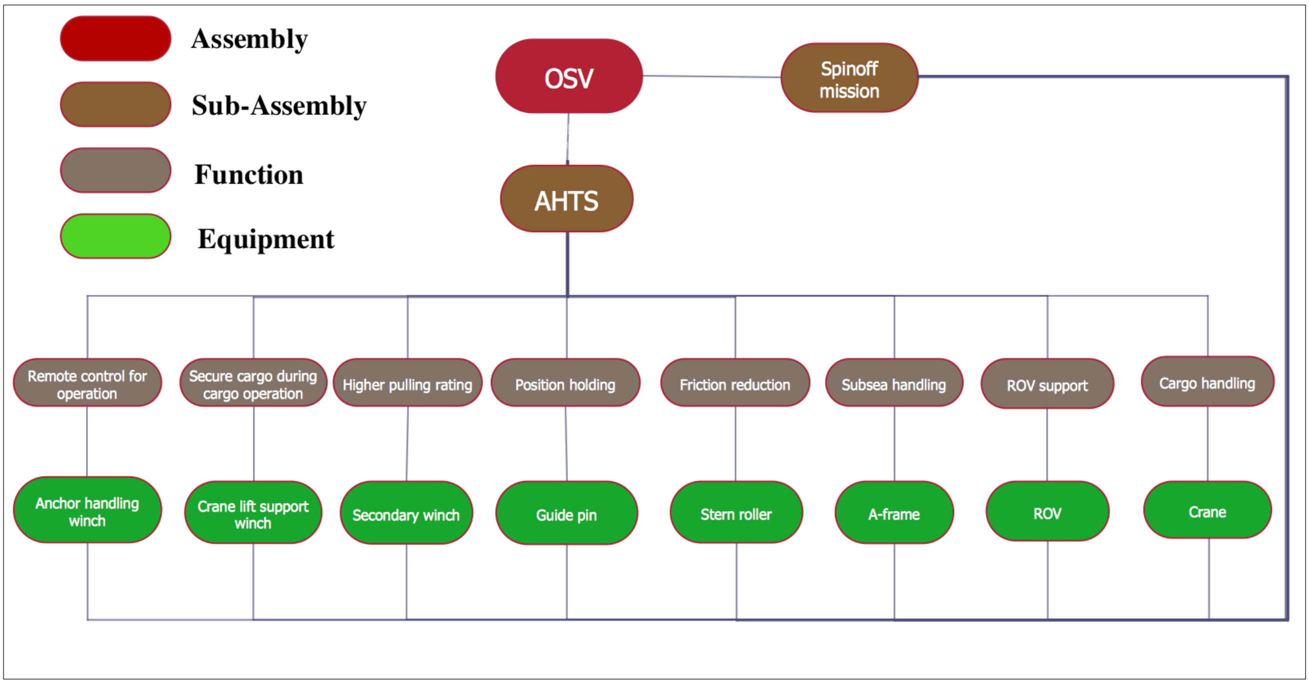


Figure 4-2 Function hierarchy of AHTS

Figure 4-2 describes the product architecture of the big case by employing the function hierarchy. There are mainly four types of level sketched with four different kinds of colours: assembly, sub-assembly, function and equipment. The meaning of each level is also introduced in the figure. As stated earlier in the case outline, the primary mission of the OSV is AHTS, thus the top level would be the OSV while AHTS stays as one of the main branch underneath the top level. The third and fourth level present the alternative potential function and its corresponding equipment respectively. Last but not least, combining some of the equipment listed in the lowest level may satisfy spinoff mission such as DSV, and it would be another branch underneath the OSV. Ship owners or operators would be satisfied with this kind of arrangement design solution as it can achieve two or more missions simultaneously.

4.3 Functionality confirmation

Throughout the product architecture, we may find that with the installation of numerous equipment on board, the vessel is possible to achieve one or more missions apart from the primary one. However, with the intention of simplifying the whole working process designed in the intelligent library, only the primary mission would be taken into consideration in the interface at the time when the ship owners or operators are required to make the selection of mission type. As assumed before, the vessel would only be assigned to a single mission at the beginning of the whole working process. The spinoff mission achieved would be considered as an extra advantage for the specific equipment-arrangement design solution, which would be a significant factor during the evaluation phase.

Apart from the definition of the primary mission for the big case, some essential predefined conditions have to be made as well before the launch of the intelligent library.

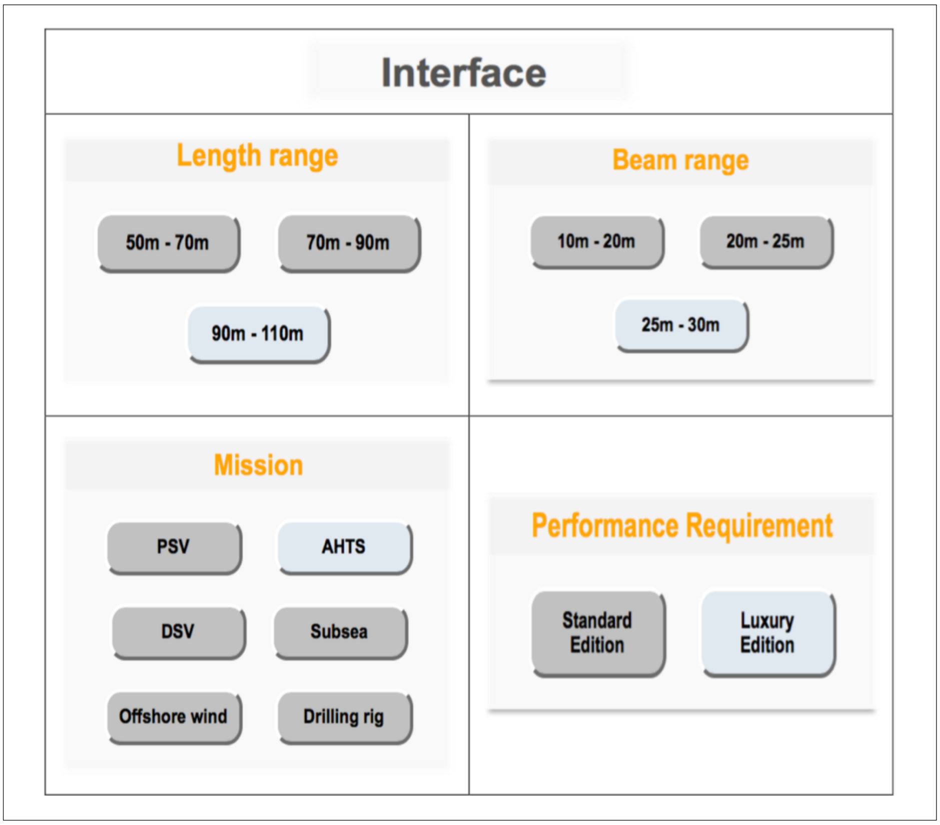


Figure 4-3 Interface of AHTS

Figure 4-3 indicates the specific choices in terms of length range, beam range, mission type and performance requirement. As the luxury edition is applied as the performance requirement, which indicates that the cost issue can be neglected in this case.

The AHTS is intended to be designed at a maximum size with luxury performance. Recalling the assumptions made earlier, further specific information could be obtained as shown in Table 4-1.

Edition	Platform	Dimensions for all main equipment and auxiliary equipment	Quantity of Auxiliary equipment			
			Mooring system	Bollard Capstan	Guide pin	Stopper
Storm	Big	Big	4	4	2	2

Table 4-1 Performance definition in big case

4.4 Main equipment listing

As the main capability is confirmed in the the interface phase, the functionality should be identified clearly here again in order to ensure that the main equipment organized in this phase would be competent to satisfy the basic essential mission requirements.

AHTS is mainly used to perform the towing operation and anchor handling supply for deployment. In order to have a better understanding about how the main equipment should be organized, the DSM would be applied here, from which we could see the filter the alternative essential main equipment.

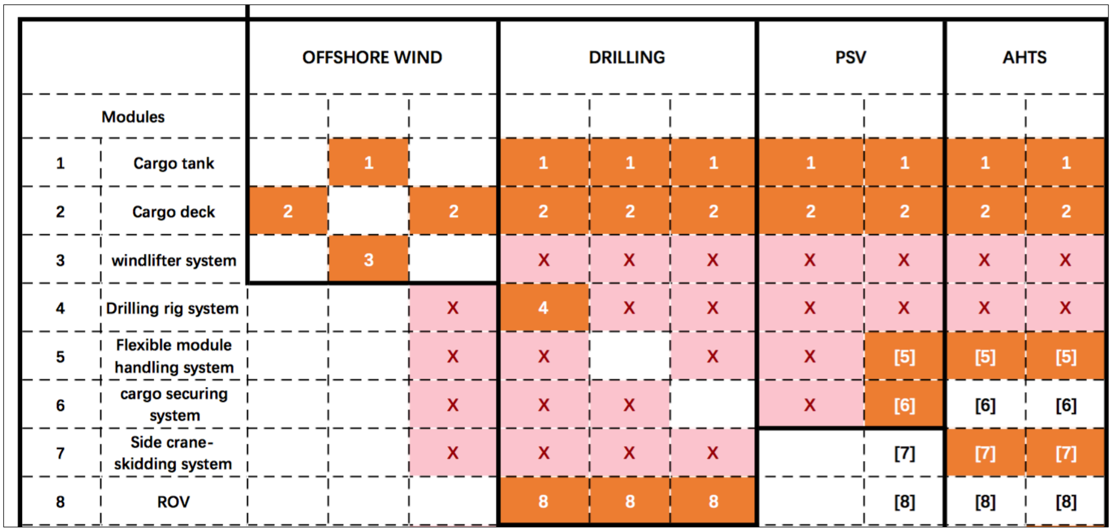
The creation of main equipment list is based on the specificity of vessel equipment functionality, which means that each equipment inside could bring about a new function that cannot replace by others. The whole DSM of AHTS is shown in the Appendix II – Design Structure Matrix, combining with the function hierarchy, we can obtain as following:

> **Essential equipment:** cargo deck, stern roller, A-frame, crane and anchor handling winch.
>
> **Optional equipment:** cargo securing system, ROV, crane lift support winch, auxiliary crane and secondary winch.

The meaning of optional equipment is not the same as auxiliary equipment which will be analysed in the later chapter. Optional equipment focuses more attention on the improvement of the vessel while the auxiliary equipment cares more about the integrity of the offshore vessel. For instance, ROV could help the vessel to do the ROV support function while auxiliary crane could improve the range of cargo handling on the basic of the installation of main crane, both the two equipment could help to improve the attribute of vessel although one is able to add one more function for the vessel while the other aims to improve the defined functionality. However, all the four kinds of auxiliary equipment aim to integrate the vessel deck equipment, in other word, all offshore vessels should be equipped with those four kinds of equipment. The auxiliary equipment can neither perform an extra function for the vessel nor improve the existing functionality.

4.4.1 DMS of AHTS

Part of the DSM of AHTS is shown in Figure 4-4, which is for illustration purpose. The relationship between equipment and mission described with number in parenthesis indicates that the equipment can be seen as an optional equipment for the mission. However, as we may notice that there are two different kinds of optional equipment: the one marked in orange and the other one without any colours. Even though both of these two expressions stand for optional, some distinctions still exist between them. The one marked in orange expresses that whether to install it on board or not depends on the performance requirement, which means it would be selected once the luxury edition is chosen as the performance requirement, and the installation of this equipment could help to accomplish the mission requirement as defined. However, the other kind of optional equipment, whose relation with mission is marked without any colours, is normally not installed under the earlier defined mission even the performance is required as luxury edition, but the reason it still remains as optional equipment is because it could achieve extra spinoff function which may help the vessel achieve more than one defined mission once it is installed, for instance, ROV is classified as one of the optional equipment, and the relation type indicates that it is not critical for AHTS mission, however, with the installation of ROV, the vessel is capable of doing the ROV support for subsea construction, which is recognized as one of the most distinctive capabilities of construction and support vessel (CSV). Therefore, once ROV is selected to be equipped on board, the vessel could achieve more than just AHTS mission, which is beneficial for ship owners or operators.



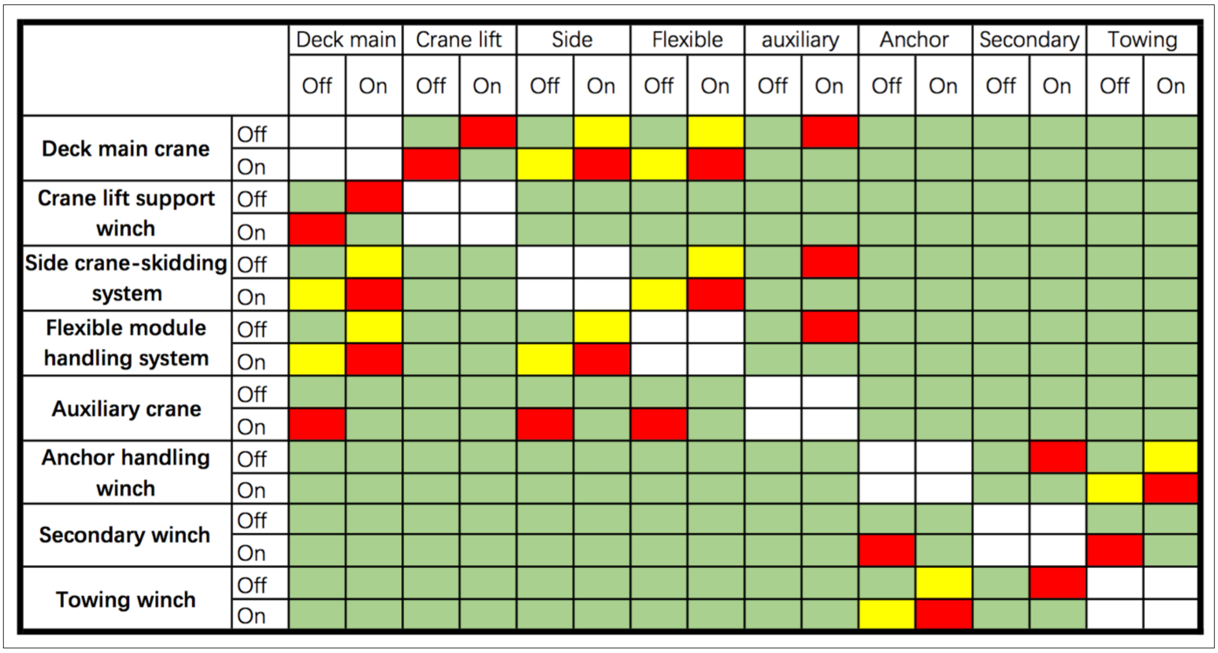
		OFFSHORE WIND			DRILLING			PSV		AHTS	
Modules											
1	Cargo tank		1		1	1	1	1	1	1	1
2	Cargo deck	2		2	2	2	2	2	2	2	2
3	windlifter system		3		X	X	X	X	X	X	X
4	Drilling rig system			X	4	X	X	X	X	X	X
5	Flexible module handling system			X	X		X	X	[5]	[5]	[5]
6	cargo securing system			X	X	X		X	[6]	[6]	[6]
7	Side crane-skidding system			X	X	X	X		[7]	[7]	[7]
8	ROV				8	8	8		[8]	[8]	[8]

Figure 4-4 Part of DSM of AHTS

Apart from the distinctive specific explanation regarding to the optional equipment, we may notice that the flexible module handling system and side crane-skidding system are classified as optional equipment, and it seems contradict with product architecture, which tends to describe crane as essential equipment. Basically, deck main crane, flexible module handling system and side crane-skidding are all belong to the 'crane' in the function hierarchy, whereas they do have their own unique features. Therefore, once we determine to select deck main crane in the DSM, the other two kinds of crane act as optional equipment.

4.4.2 Compatibility matrix of AHTS

In fact, at the time when deck main crane is determined to be installed on board, side crane-skidding system and flexible module handling system cannot even stay as optional choices which depend on the performance factor to determine to be selected as they share the same location and perform the function more or less the same as each other, and this will be solved by the compatibility matrix.



		Deck main		Crane lift		Side		Flexible		auxiliary		Anchor		Secondary		Towing	
		Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On
Deck main crane	Off	⬜	⬜	🟩	🟥	🟩	🟨	🟩	🟨	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩
	On	⬜	⬜	🟥	🟩	🟨	🟥	🟨	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Crane lift support winch	Off	🟩	🟥	⬜	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	On	🟥	🟩	⬜	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Side crane-skidding system	Off	🟩	🟨	🟩	🟩	⬜	⬜	🟩	🟨	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩
	On	🟨	🟥	🟩	🟩	⬜	⬜	🟨	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Flexible module handling system	Off	🟩	🟨	🟩	🟩	🟩	🟨	⬜	⬜	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩
	On	🟨	🟥	🟩	🟩	🟨	🟥	⬜	⬜	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Auxiliary crane	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	🟩	🟩	🟩	🟩	🟩	🟩
	On	🟥	🟩	🟩	🟩	🟥	🟩	🟥	🟩	⬜	⬜	🟩	🟩	🟩	🟩	🟩	🟩
Anchor handling winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	🟩	🟥	🟩	🟨
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	🟩	🟩	🟨	🟥
Secondary winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	⬜	⬜	🟥	🟩
Towing winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟥	⬜	⬜
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥	🟩	🟩	⬜	⬜

Figure 4-5 Part of compatibility matrix of ATHS

The core section of the compatibility matrix applied in AHTS mission is shown in Figure 4-5while the whole matrix is in appexidx. The objective of this compatibility matrix is to find out whether two equipment can be installed on board simultaneously according to the interactions between each other. Interactions between equipment generated in the matrix are classified into three kinds: compatible (marked in ‘green’), restricted (marked in ‘yellow’) and prohibited (marked in ‘red’).

As agreed in the earlier stage, AHTS is the primary mission for the vessel to perform, and this implies the indispensability of some related equipment. Towing winch is considered as an essential equipment in normal offshore vessel whereas it has to be replaced by anchor handling winch in AHTS mission not only because they are contradictory, but also on account of the functionalities they can offer for the vessel are more or less the same. Deck main crane, flexible module handling system and side crane-skidding system are all branches of ‘crane’ part which is necessary equipment for AHTS mission, the functions these three branches perform are almost the same even though subtle distinctions in terms of the working boundary could be identified among them, only one of those three units could be determined to install on board due to the location overlap. Besides, the auxiliary crane could only be considered as an optional equipment after the installation of one of those three crane branches, the same principle applies to the secondary winch and anchor handling winch.

4.5 Auxiliary equipment management

Unlike main equipment which determines the attribute of the offshore vessel, auxiliary equipment focus more attention on the integrity of existing vessel performance, and the performance requirement is the core factor to the decision with respect to the quality and quantity of auxiliary equipment. With the purpose of process simplification, the auxiliary equipment part is assumed to consist of mooring system, bollard capstan, guide pin and stopper. Since the locations of all the four equipment are small and have no intersections with the main equipment which occupies far larger space, the compatibility matrix would not be applied either with internal equipment nor with the main equipment.

As agreed earlier in the interface phase, the performance requirement is selected as luxury edition, which implies that the quantity of each kind of auxiliary equipment is at the maximum number. Therefore, all the alternative potential arrangement design solutions would contain four bollard capstans, four mooring systems, two guide pins and two stoppers.

4.6 Performance consideration

In order to simplify the process, only four common types of auxiliary equipment are stored in the intelligent library to generate the arrangement design solution whereas the quantity of each auxiliary equipment is determined by the performance requirement, which determines the quantity of each main equipment simultaneously. Most main equipment can only be installed one for an offshore vessel except for cargo securing system, auxiliary crane and secondary winch. As defined in the earlier phase, luxury edition is selected as the performance requirement. Following comes the corresponding quantity of the four special main equipment in luxury edition.

Equipment	Quantity
Cargo securing system	2 or 4
Auxiliary crane	2
Secondary winch	2

Crane is one of the indispensable equipment for AHTS, and there are three possible crane types which has been stated before. As the performance is luxury edition, which means all essential and optional equipment inside main equipment will be installed on board. Due to the location overlap issue, only two cargo securing systems could be equipped once the crane is determined in the form of deck main crane or flexible module handling system. However, if the crane is selected in the form of side crane-skidding system, the quantity of cargo securing system could be reach four, and that is why the quantity of cargo securing system is 2 or 4. Besides, once both deck main crane and one side crane-skidding are determined to be install on board simultaneously, the spare space in vessel can only hold two cargo securing systems, and the specific reason for this arrangement would be explained in the later chapters.

4.7 Input summary

Both main equipment and auxiliary equipment have been analysed in terms of the possibility and quantity. The alternative potential arrangement-making solutions, which combine both main function-oriented equipment and potential performance-optimization-oriented equipment, are possible to be summarized, and all the arrangements should take the space balance and weight balance into consideration in order to avoid location overlap.

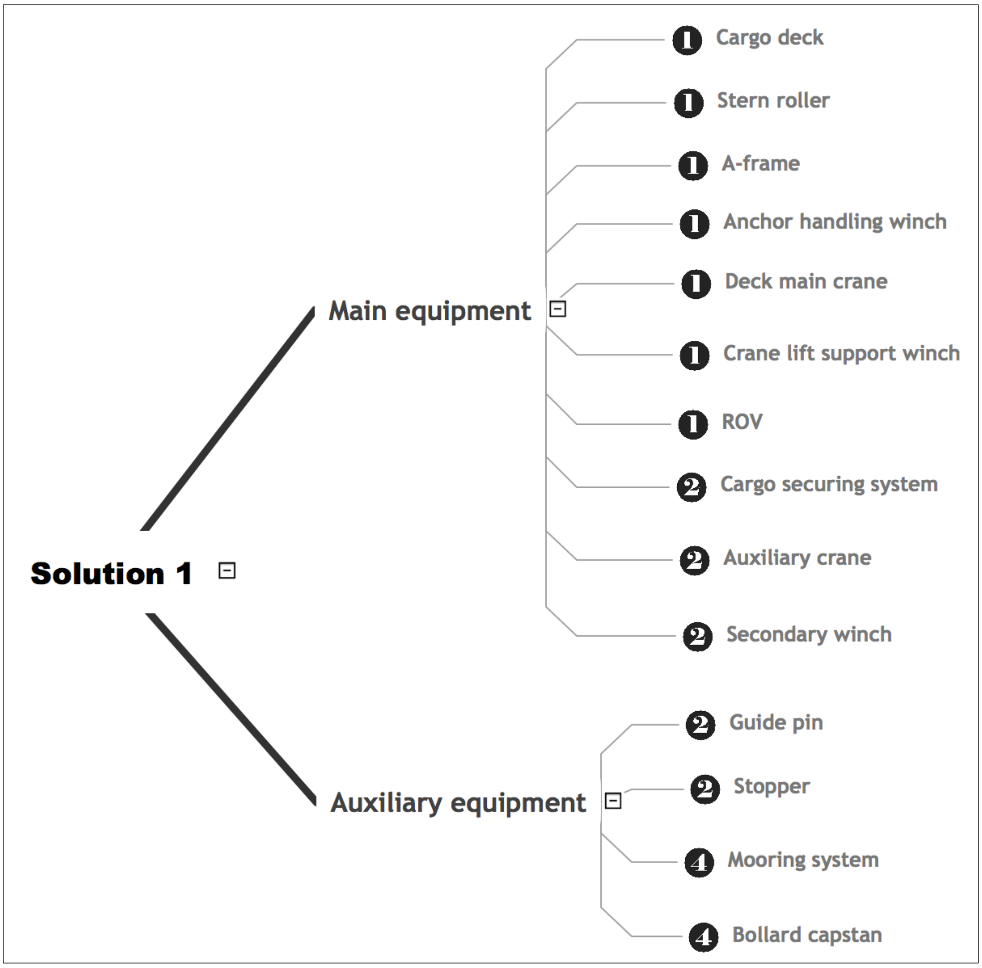


Figure 4-6 Equipment list of alternative arrangement solution

On the basic of the data from DSM and compatibility, considering all the requirements defined in the interface, four potential equipment arrangement design solutions are proposed. One of the four equipment list of alternative arrangement design solutions is shown in Figure 4-6 while the other three can be found in Appendix III – Solution Input Summary, specific information with respect to the designation and quantity of each equipment is provided in the list.

4.8 Arrangement-making

Three alternative equipment arrangement-making solutions are proposed according to the mission requirements. Based on the process algorithm of the intelligent library, corresponding 2D arrangement drawing would be further made by employing a web-based APP developed by H. M Gaspar (2015) in order to give both ship designer and ship owner a direct view about how the arrangement would be like once all main and auxiliary equipment are installed on board. following comes three arrangement sketches and corresponding explanation regarding to the design principle.

4.8.1 Product platform

Intelligent library has proposed three representative samples of product platform with different dimensions and length-width ratio, which, is the prototype of cargo deck based on the alternative dimension choices of the offshore vessel appear in the interface. Since cargo deck is the foundation of the deck equipment arrangement, the dimension of product platform should be confirmed first.

Length-width ratio of product platform is not only related to the dimension of ship, but also based on the performance requirements. Brief description regarding to the product platform has been introduced in the 'functionality confirmation' phase after the luxury edition has been considered as the performance requirement, and the further specific length-width ratio of product platform is presented in Table 4-2 according to the dimension of the offshore vessel.

Length	Beam	Length-width ratio of product platform (Luxury edition)
From 90m to 110m	From 25m to 30m	98 : 30 (big)

Table 4-2 Definition of product platform

4.8.2 Equipment-arrangement solutions

In order to have a better understanding about the four alternative arrangement solutions, four tables with respect to the specific information of each choosing equipment in terms of the designation and corresponding colour signal in each arrangement would also be provided along with the drawings.

- **Solution 1**

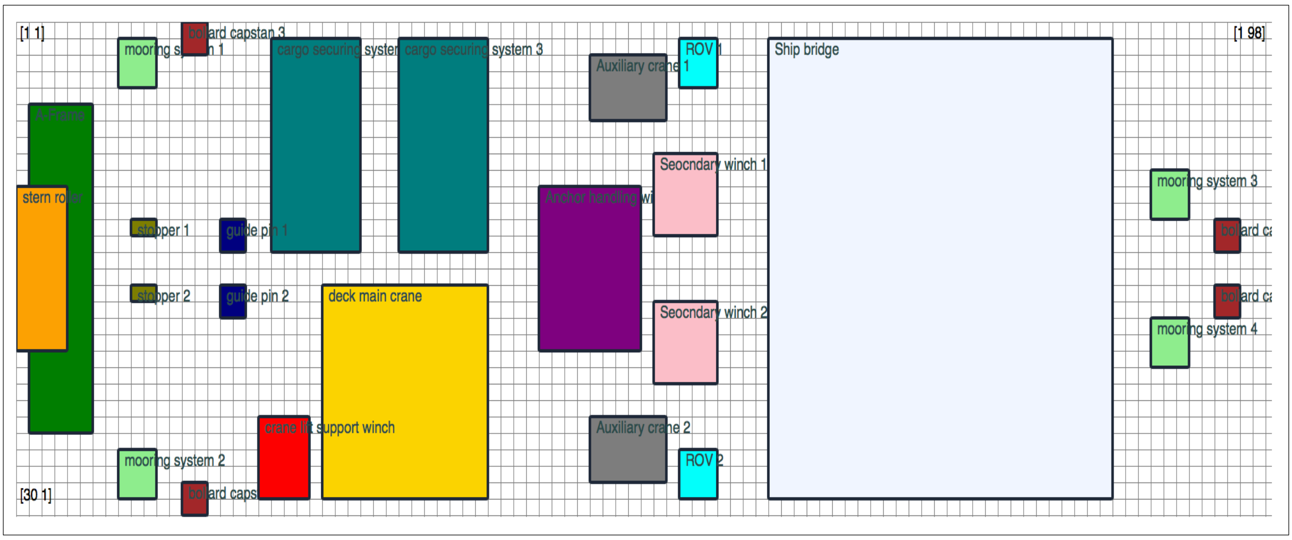


Figure 4-7 Equipment-arrangement solution 1

Equipment	Colour signal	Equipment	Colour signal
Stern roller	Orange	A-Frame	Green
Mooring system	Lightgreen	Bollard capstan	Brown
Stopper	Olive	Guide pin	Navy
Cargo securing system	Teal	Deck main crane	Gold
Crane lift support winch	red	Anchor handling winch	Purple
Auxiliary crane	Grey	Secondary winch	Pink
Ship bridge	Aliceblue	ROV	AQUA

Table 4-3 Equipment designation and colour signal in solution 1

Table 4-3 lists all main and auxiliary equipment employed by solution 1, and the virtual arrangement drawing is shown in Figure 4-7. The web-based APP, which is the arrangement making tool, employs numerous small block units, and the dimension of each unit is 1×1. As the product platform (cargo deck) is the luxury edition, which implies the length-width ratio is 98:30, therefore the whole cargo deck contains 98 block units in each row and 30 block units in each column. The employment of the APP is to simulate the cargo deck, therefore the first column denotes the stern while the 98th means the bow, and the first row and 30th row represents the two shipboards. Ship bridge exists in each kinds of offshore vessels, therefore a certain space has to be saved for its placement. Intelligent library has set the location and size of ship bridge as a default based on the specific performance requirement and vessel dimension, which, can be found as the ‘Aliceblue’ block in the arrangement drawing of solution 1.

AHTS is the defined mission in this case, combining with the discussion regarding to the main and auxiliary equipment made in the previous phase, the variety of auxiliary equipment could be confirmed first. Furthermore, based on the performance requirement (luxury edition), the quantity of auxiliary would be obtained, not only that, but the information of some of the main equipment (anchor handling winch, stern roller, A-frame, auxiliary crane, secondary winch) could also be determined in terms of both variety and quantity. Therefore, there are only 5 main equipment which remains uncertain.

As the solution 1 set the deck main crane as the form of ‘crane’ class, based on the DSM and equipment compatibility matrix, we could further realize that crane lift support winch should be installed simultaneously. Last but not least, due to the location overlap issue, only two cargo securing system could be installed in this arrangement. The dimension and location of each equipment block change along with the size of the product platform (cargo deck), and they are set as the system default that cannot be modified.

Inside the Figure 4-7, we may also notice that there are overlapped blocks between the stern roller and A-frame. This is permissible because of their spatial positions of these two equipment, the drawing presented here is more like a top view of the equipment on board, and it cannot tell the altitude of each equipment. The whole stern roller is installed on the cargo deck while the A-frame only has two support frames connected to the deck, the overlapped part between A-frame and stern roller is the cantilever of A-frame, which is much higher than the cargo deck.

- **Solution 2**

Instead of using deck main crane, solution 2 employs the flexible module handling system, which implies the forsake of deck main crane and side crane-skidding system. Also, crane lift support winch, which is particularly installed for deck main crane, is also abandoned. As the flexible module handling system would stretch from one shipboard to the other, one of the cargo securing system has to be cancelled. However, a new cargo securing system can be created by replacing the location of crane lift support winch.

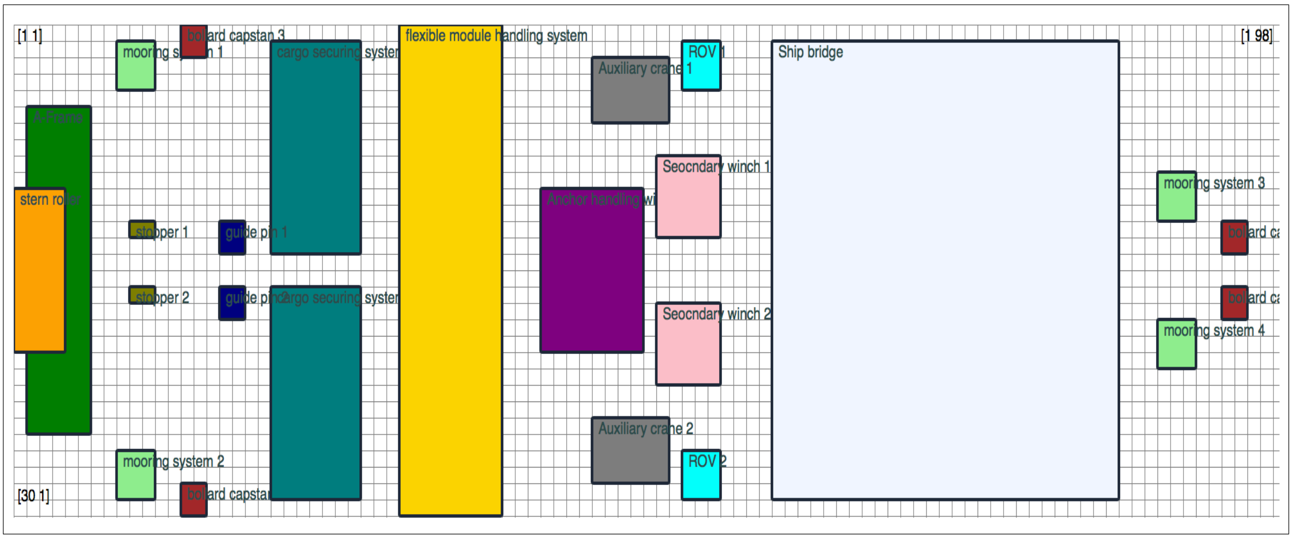


Figure 4-8 Equipment-arrangement solution 2

Equipment	Colour signal	Equipment	Colour signal
Cargo securing system	Teal	A-Frame	Green
Mooring system	Lightgreen	Bollard capstan	Brown
Anchor handling winch	Purple	Guide pin	Navy
Ship bridge	Aliceblue	Stern roller	Orange
Auxiliary crane	Grey	Secondary winch	Pink
Flexible module handling system	Gold	Stopper	Olive
ROV	AQUA		

Table 4-4 Equipment designation and colour signal in solution 2

- **Solution 3**

Solution 3 comes with the employment of side crane-skidding system, which indicates the abandon of the other two forms of 'crane' class. Like the explanation regarding to the overlap between stern roller and A-frame, the same principle applies between side crane-skidding system and cargo securing system, cargo securing systems are installed invariably on the cargo deck while the side crane-skidding system located in two shipboards, and the orbits of the side crane-skidding system are higher than the cargo deck. However, even though there's no overlap between side crane-skidding system and cargo securing system, the cargo securing system has height limitation for the storage of the cargos, which means that the cargos should shorter than the orbits of side crane-skidding system, otherwise they would cause damage to the side crane-skidding system.

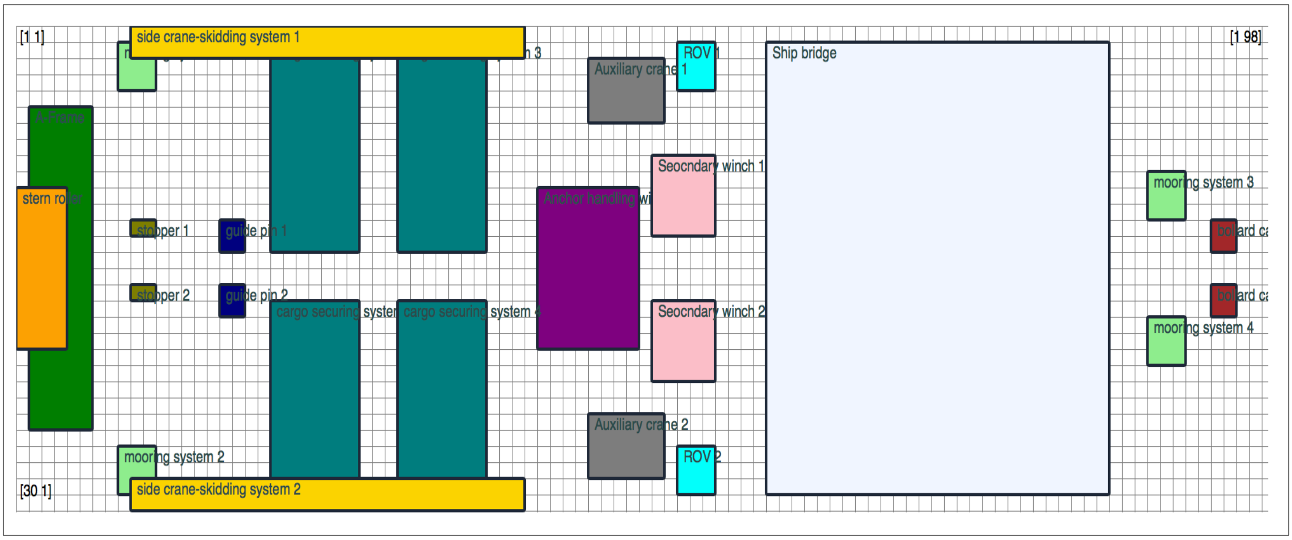


Figure 4-9 Equipment-arrangement solution 3

Equipment	Colour signal	Equipment	Colour signal
Cargo securing system	Teal	A-Frame	Green
Mooring system	Lightgreen	Bollard capstan	Brown
Anchor handling winch	Purple	Guide pin	Navy
Ship bridge	Aliceblue	Stern roller	Orange
Auxiliary crane	Grey	Secondary winch	Pink
Side crane-skidding system	Gold	Stopper	Olive
ROV	AQUA		

Table 4-5 Equipment designation and colour signal in solution 3

- **Solution 4**

Got inspired from the solution 1 and solution 3, the 4th solution proposes the combination of deck main crane and side crane-skidding system. These two units both belong to the ‘crane’ part, whereas they do have their own unique characteristic, which indicates that this cooperation could ulteriorly optimize the mission performance. As the synergic equipment, crane lift support winch should also be equipped along with the deck main crane. Besides, two cargo securing systems could also be installed under the orbit of side crane-skidding system. Specific arrangement and equipment listing could be seen in Figure 4-10 and Table 4-6 respectively.

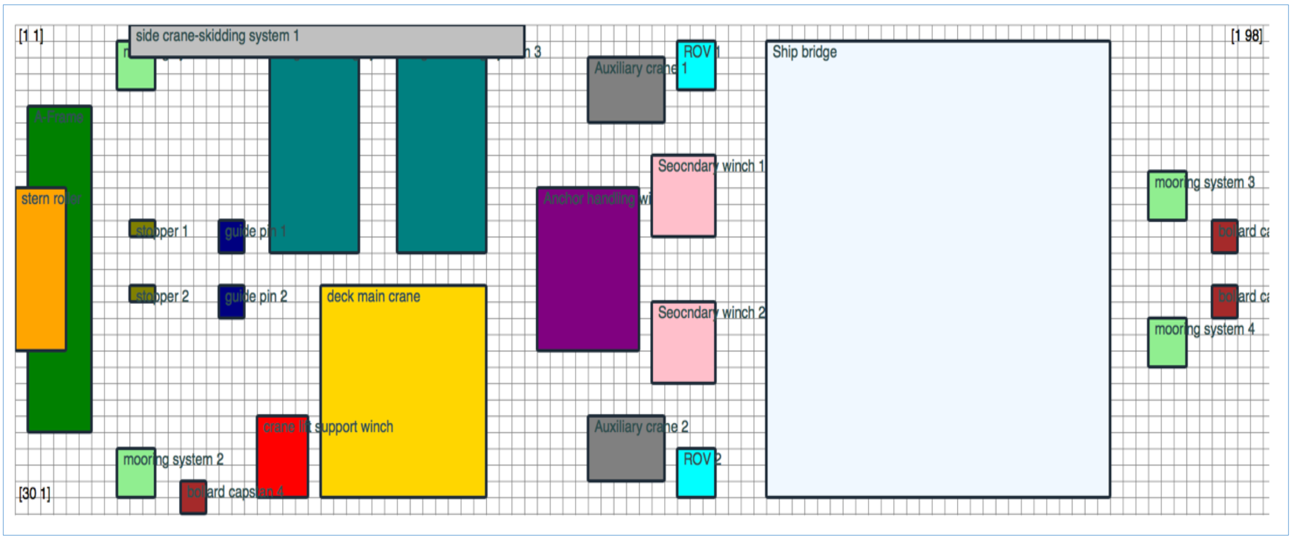


Figure 4-10 Equipment-arrangement solution 4

Equipment	Colour signal	Equipment	Colour signal
Cargo securing system	Teal	A-Frame	Green
Mooring system	Lightgreen	Bollard capstan	Brown
Anchor handling winch	Purple	Guide pin	Navy
Ship bridge	Aliceblue	Stern roller	Orange
Auxiliary crane	Grey	Secondary winch	Pink
Side crane-skidding system	Sliver	Stopper	Olive
ROV	AQUA	Deck main crane	Gold
Crane lift support winch	red		

Table 4-6 Equipment designation and colour signal in solution 4

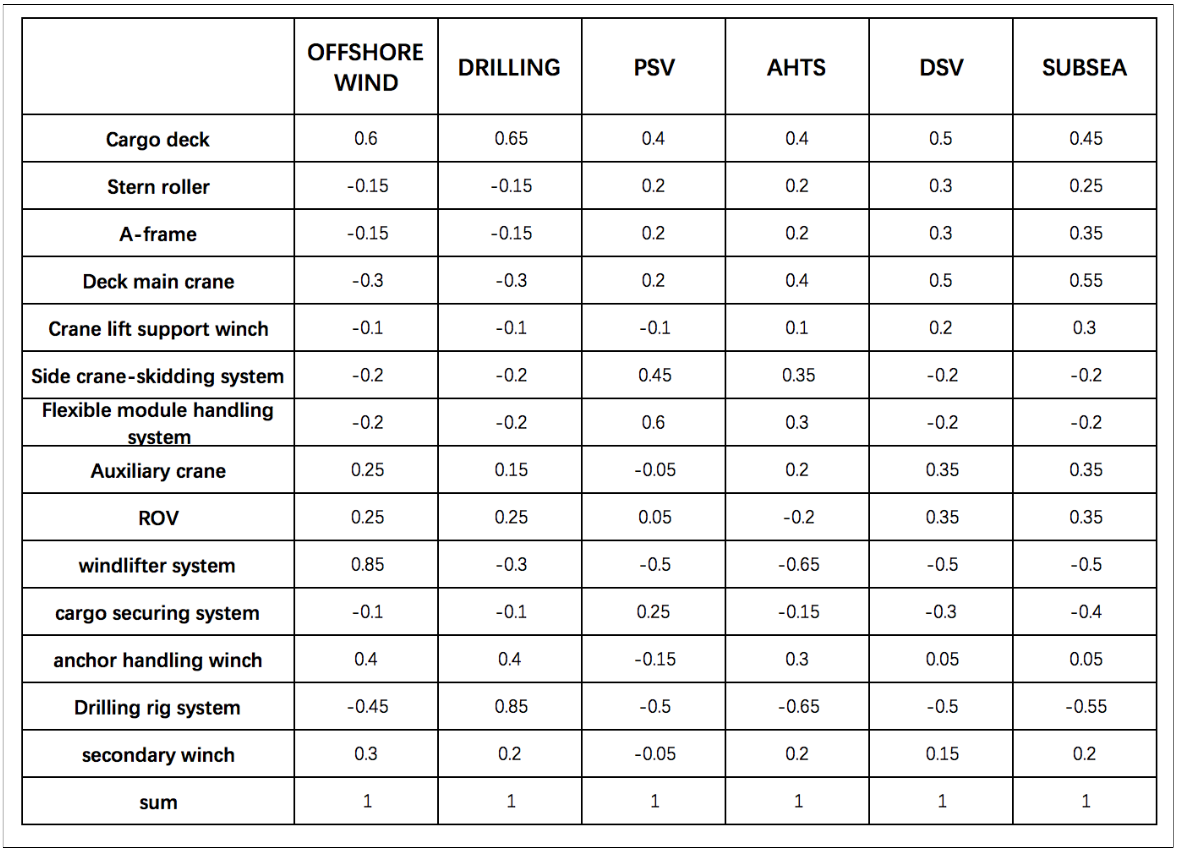
4.9 Evaluation

According to the defined mission requirements, four equipment arrangement solutions and corresponding description regarding to the principles are made by the web-based APP so far, but this is still not the final results. The approach employed by the intelligent library skilfully embeds the spiral system into the whole design procedure, which indicates that there will be a relatively better equipment arrangement-making solution presented after the entire intelligent procedure. Through the drawings based on the employment of different combination of equipment, we may notice there are differences between each other, and people may have different preference among those arrangement-making solutions, whereas there’s no theory behind the specific choice. Therefore, in order to figure out a relatively better arrangement among the three alternatives, specific comparison has to be made in the evaluation phase.

As was stated in the earlier stage, luxury edition is selected to be the performance requirement in this AHTS mission big case, thus cost issue is no long be considered as a comparable factor, which makes the comparisons in relation to the operation performance appear to be particularly significant for electing the better arrangement-making solution.

The whole evaluation phase would rely on the Mission-Modules Relationship Table (MMRT), which specifically describes how necessary one equipment is for performing each potential mission by grading ‘equivalent’ credit. The credit varies from -1 to 1, higher positive score would be given to the equipment which is particularly essential for the given mission, whereas low negative score would be arranged to the equipment which is not beneficial for performing the given mission.

Table 4-7 shows the MMRT set in the intelligent library. Statement regarding to the principle of MMRT has to be announced here again: the creation of this MMRT is not criterion, which means MMRT may vary from ship designer to ship designer.



	OFFSHORE WIND	DRILLING	PSV	AHTS	DSV	SUBSEA
Cargo deck	0.6	0.65	0.4	0.4	0.5	0.45
Stern roller	-0.15	-0.15	0.2	0.2	0.3	0.25
A-frame	-0.15	-0.15	0.2	0.2	0.3	0.35
Deck main crane	-0.3	-0.3	0.2	0.4	0.5	0.55
Crane lift support winch	-0.1	-0.1	-0.1	0.1	0.2	0.3
Side crane-skidding system	-0.2	-0.2	0.45	0.35	-0.2	-0.2
Flexible module handling system	-0.2	-0.2	0.6	0.3	-0.2	-0.2
Auxiliary crane	0.25	0.15	-0.05	0.2	0.35	0.35
ROV	0.25	0.25	0.05	-0.2	0.35	0.35
windlifter system	0.85	-0.3	-0.5	-0.65	-0.5	-0.5
cargo securing system	-0.1	-0.1	0.25	-0.15	-0.3	-0.4
anchor handling winch	0.4	0.4	-0.15	0.3	0.05	0.05
Drilling rig system	-0.45	0.85	-0.5	-0.65	-0.5	-0.55
secondary winch	0.3	0.2	-0.05	0.2	0.15	0.2
sum	1	1	1	1	1	1

Table 4-7 Whole Mission-Module Relationship Table (MMRT)

Comparing those four alternative equipment-arrangement solutions, it could be summarized that the main difference is the form of crane appears in a variety of forms: deck main crane (solution 1), flexible module handling system (solution 2), two side crane-skidding systems (solution 3) and combination of deck main crane and one side crane-skidding system (solution 4). Apart from the main defined mission—AHTS, All the three solutions are capable of performing two spinoff missions—PSV and Subsea support, and they are supported by cargo securing system and ROV respectively. Due to the location overlap issue, solution 1, solution 2 and solution 4 could only be arranged 2 cargo securing system respectively, whereas 4 same units could be installed in solution 3. Therefore, solution 3 appears to be a better choice in performing one of the spinoff mission—PSV. As all solutions are designed to equip 2 ROV on board, thus the four solutions are equivalent to each other in operating the subsea support mission. Combining the mission requirements and the four alternative solutions, it can be obtained that all the solutions satisfy the basic demands, in other word, equipment inside each arrangement is enough to perform the required mission—AHTS, therefore further comparison would be made in terms of the specific performance in order to make a necessary choice.

In order to generate the a relatively better arrangement solution, the comparison of the summation of the credit which describe the performance of each equipment in each arrangement in performing AHTS appears to be the most reasonable methodology as all the other equipment in those arrangement solutions are the same as each other. Crane lift support winch works as an assistant for the deck main crane, and it do have a positive effect in performing the AHTS. With the help of MMRT, solution 4 finally stands out to be the better arrangement design for performing AHTS mission as its total credits are higher than the other three solutions, the subtle clue of which could actually be found in the equipment listing: combining deck main crane and side crane-skidding system, both of which have the ability to improve the vessel performance somehow.

Picking up the evaluation of the four solutions in performing spinoff missions, we may notice that solution 3 which owns four cargo securing systems appears to be a better one to operate PSV mission, however, as the main mission that defined in the early stage is AHTS, the attention should be focused in AHTS-based performance. Therefore, the arrangement which employs both deck main crane and side crane-skidding system is evaluated to be a better equipment-arrangement design solution for performing the AHTS mission in the big case.

4.10 Better arrangement-solution making

The core idea of 3D arrangement method is based on the concept of module design and carried out by Siemens-NX. A common scalable platform is constructed by means of the idea of product platform, different kinds of equipment can be further configured here to compose diverse arrangement-design solutions.

The web-based APP is characterized by its convenience and conciseness, and it is employed to sketch the manifestation of alternative arrangement design solutions in the arrangement-making phase. However, the drawings presented by the web-based APP is a 2D, and it is more like a top view of the deck equipment in the vessel. As both ship and equipment are 3D products, thus it is much more realistic and persuasive to make the 3D arrangement, and besides, the arrangement layout presented by the web-based APP cannot describe the altitude of each product, which, may hard to explain some overlap issues between some equipment in the arrangement.

As the 4th solution is evaluated as the better arrangement design solution for AHTS after the comparison made in the previous phase, therefore the corresponding 3D arrangement layout would be simulated with the help of Siemens-NX in this stage. The general view of 4th solution is shown in Figure 4-11, equipment employed in this design is substituted by several blocks of various sizes based on the dimension of each equipment (More 3D figures can be seen in Appendix IV – 3D Virtual Arrangement).

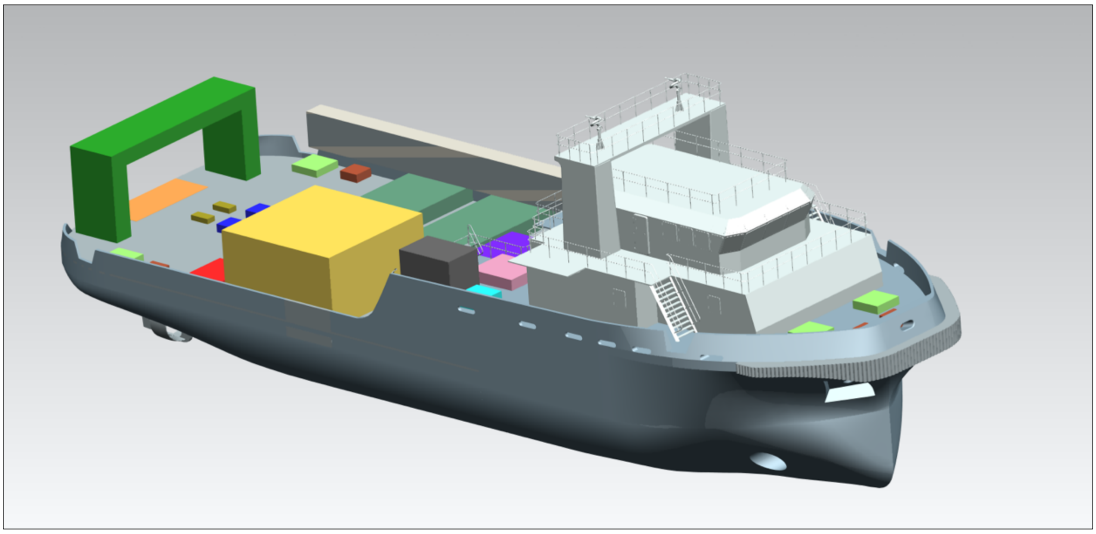


Figure 4-11 Better arrangement in 3D

The sizes of equipment blocks are based on the dimension of each equipment which has been described in the arrangement-making phase. Figure 4-12 displays the top view of the vessel employs the 4th arrangement design solution. The layout in 3D is in accordance with the 2D arrangement design made in web-based APP, including the colour and dimension of each kind of equipment block.

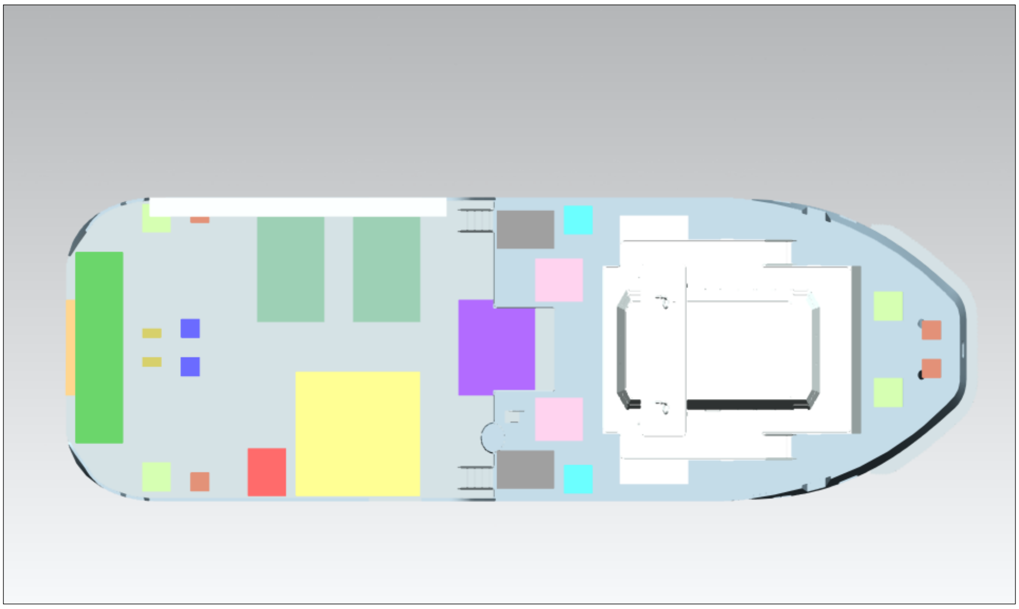


Figure 4-12 Top view of 3D arrangement

One of the most significant reason to employ Siemens-NX to present the final arrangement design in 3D is because the drawings made by the web-based APP have a fatal deficiency, which, is the altitude of each equipment. As can be seen in the sketches presented by the web-based APP, the locations of some equipment are overlapped with each other, which, is due to the angle of matter, and in fact those overlaps don't exist in space. However, even if some corresponding explanations are described along with the overlap issue, it is still hard to have an intuitive feeling about causations. Therefore, the virtual 3D arrangement of the relatively better design solution is made in order to have a specific view about the whole equipment-arrangement layout. Also, some doubts with regard to the design could be clearly explained in the 3D model, for instance, stern roller and A-frame do not have any overlaps in terms of the locations, and the same applies to the side crane-skidding system and cargo securing systems.

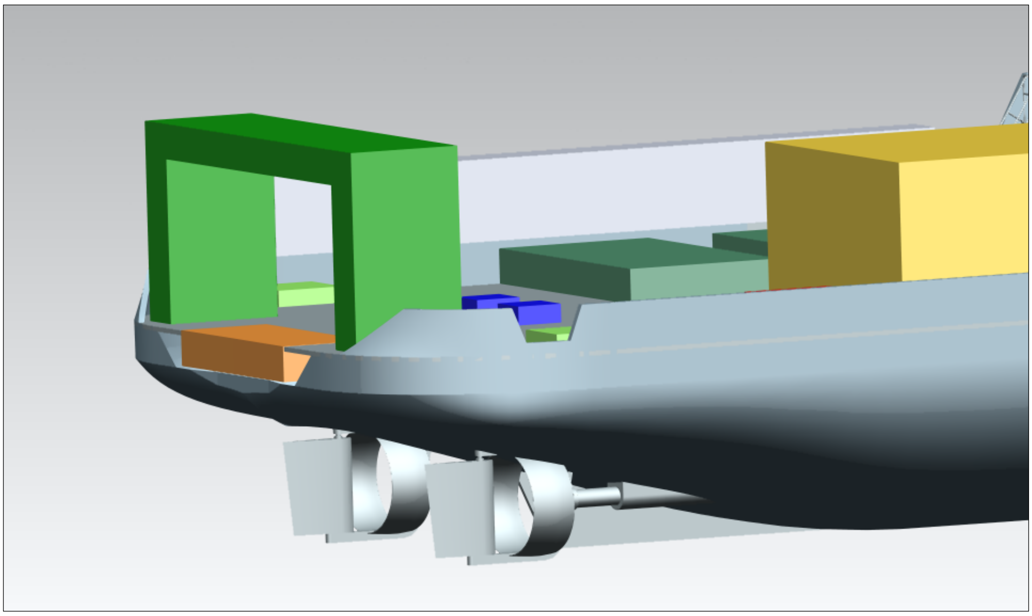


Figure 4-13 specific view of 3D arrangement

The equipment compatibility matrix is applied inside the process in order to study the possibility of arranging two different kinds of equipment in the same arrangement design solutions simultaneously. The overlapped location is the main issue for preventing two or more equipment to appear in one arrangement design solution, and this problem can be clearly identified in the 3D model. For instance, the 4th solution employs only one crane-skidding system, whereas the location of the other side crane-skidding system is replaced by the deck main crane, and the location of the two equipment overlap with each other. Figure 4-14 shows the result of equipping both the deck main crane and two side crane-skidding systems on board, and the location problem can be clearly identified through the virtual arrangement-making..

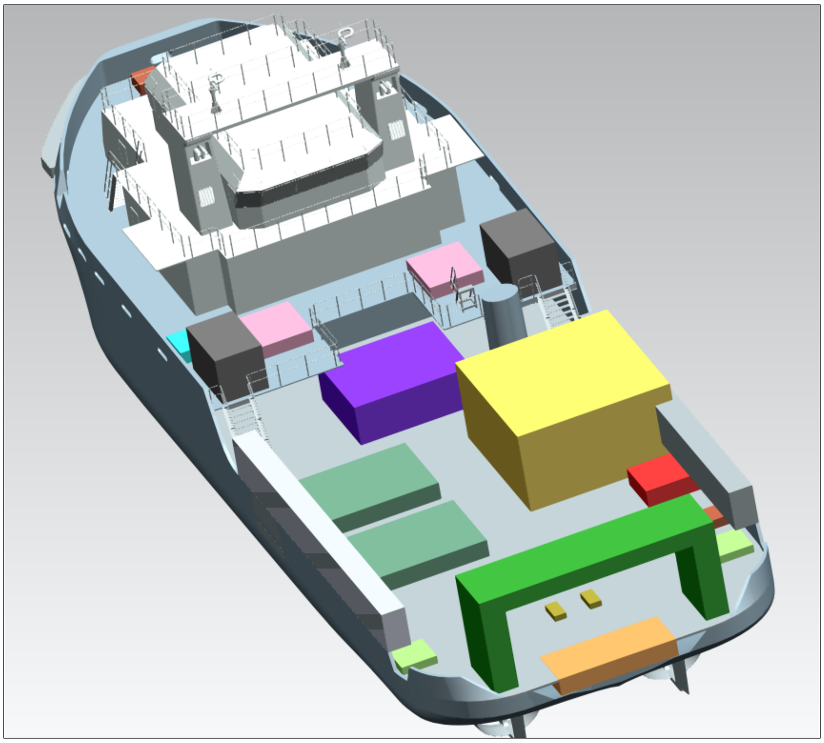


Figure 4-14 Overlap issue illustration

4.11 Discussion

The main objective of constructing the intelligent library is to shorten the time of generating the alternative deck equipment-arrangement design solutions according to the various mission requirements. The complexity of ships and the complexity of the ship design process make it hard to generate an emergent equipment-arrangement design solution able to satisfy the mission requirements, and throughout the case, some deficiencies could then be summarized.

In order to simplify the whole working process, the OSV is assumed to be assigned to only one single mission in the definition phase, whereas it is much normal for ship owner or operator to require the OSV to be able to perform two or more missions simultaneously. As OSV could be divided into numerous specific missions, therefore the constraint regarding to the mission definition should be as fewer as possible.

In order to simplify the working procedure and operate the intelligent library much more swimmingly, a certain number of equipment is listed in the main equipment list and further applied into this study. Each equipment is assumed to be capable of either develop a new function or improve the mission performance, and those functions cannot be achieved by any other equipment. In fact, as there are numerous specific mission types under the OSV, the corresponding equipment is more than listed in this study, moreover, there do have some equipment that can perform the same functions, and those types of equipment should also be considered to input the data-based library. As a result, the DSM should be reconstructed in order to figure out the relations between all the potential equipment and missions. Besides, as equipment inside the library may perform the similar functions, huge modifications would be made in the equipment compatibility matrix aiming for grasping the interactions between equipment. Last but not least, the definition of auxiliary equipment aims to help to integrated the whole deck equipment arrangement for the vessel, four equipment is analysed in this study with the purpose of simplify the working procedure, whereas more should be employed, which would make the intelligent library much more practical and rational.

However, even more main and auxiliary equipment are proposed to be stored inside the data-based library, limitations regarding to the types of equipment are still essential to be defined with the purpose of not make the intelligent library on the verge of becoming unmanageable. Nevertheless, fewer constraints are projected to put in the mission definition phase, which indicate that more equipment would be employed and applied into alternative arrangement solutions. Therefore, it becomes a significant issue to make the balance in relation to the scope of the equipment.

5 CONCLUSION

The main objective of the intelligent library is to generate a relatively better equipment arrangement design solution according to the various mission requirements. As ship is a huge complex product, which contains numerous kinds of equipment, therefore the construction of the intelligent library is in a continuously development. Inside this study, three main concepts (product architecture, module design and product platform) are proposed and applied into the intelligent library to ensure the specific scope, along with three approaches (DSM, equipment compatibility matrix and MMRT), which assist to accomplish the task settled in each steps of the whole process.

In shipbuilding history, ship design is an individual process, each product always developed once at a time. Normally, it takes ship designers quite a long time to generate the corresponding arrangement design solutions. Therefore, it attracts out attentions and soon brings about an interesting subject—how to generate the arrangement design solution based on the various mission requirements much quicker and more efficient. Ship arrangement has huge amount of work, and it could be divided into hull structural arrangement, machinery arrangement and equipment arrangement in specific, once all the arrangement design solutions are expected to be designed and developed by the intelligent library, that's hardly to success. Therefore, the equipment arrangement is analysed to be the main design topic for the intelligent library as the equipment is suitable to be stored inside the data-based library.

Due to the complexity of ships and ship design process, soon we realize that the scope has to be narrowed down again as there are too many kinds of equipment in a vessel, and that is why product platform is applied inside. This concept divides the vessel into two parts— 'mission' and 'platform'. The core idea is to construct a common scalable platform, and equipment could be further configured here to compose alternative arrangement design solutions. It is assumed that the functionality-related equipment is mainly in the 'mission' part, whereas some of the function-oriented equipment do also exist in the 'platform' part, which is neglected for simplification purpose. Product platform has been applied into car industry for a long time, and it should be a good approach to be employed in ship design, whereas the method remains to be reconsidered and optimized.

The methodology developed inside the intelligent library aims to generate the relatively better arrangement design solution for one of the specific given mission based on a certain number of equipment stored in the data-based library. The employment of DSM assists to classify the relations between alternative equipment and defined mission into four categories: essential, potential, dispensable and dangerous. Further, the equipment compatibility matrix gives a great overview about the possibility of the installation of two equipment, which, is a critical reference indication. Last but not least, as the cornerstone of evaluation phase, the MMRT specifically describes the dependency level of one equipment to a mission, aiming to reveals the relatively better design solutions among the alternative choices, which, is as proposed to be the final achievement of the intelligent library. However, the creations of MMRT is much more flexible, which indicates that the dependency degree for one equipment to a mission varies from ship designers to ship designers. Therefore, it would be convinced once MMRT can be developed to be a criterion for evaluation.

The case study describes in specific how the methodology is applied in a real case—AHTS, along with the feedback of the feasibility of the methodology. The case shows that a relatively better arrangement design solution could be able to generated step-by-step following the process algorithm. The reason for defining the AHTS as luxury edition is because of the cost issue, which is confidential and hard to collect the relevant data. In fact, the cost of each arrangement design solution can be considered as a vital factor when making comparisons between alternative arrangement design solutions. In spite of some deficiencies and limitations, it is still a good start to attempt the intelligent library in ship industry, and through both the employment of advanced concepts and methods, we could realize that the whole process is better-arrangement-oriented, which, is exactly the proposed objective of constructing the intelligent library.

6 FUTURE PROSPECTS

Being able to generate a corresponding arrangement according to the various mission requirements in a rapid way has been proposed in many years, whereas the progress moves slowly due to the complexity of ship and the complexity of ship design process. This study proposes to establish a data-based library with 'smart algorithm' developed inside to generate the relatively better equipment arrangement-making design solution, and through a case attempt which is used to see the feasibility of the methodology, there are some possible steps to develop the intelligent library. This chapter classify the deficiencies into two aspects: methodology and simulation.

Methodology

As offshore support mission can be decomposed into numerous specific sub-missions, equipment required by those sub-missions would therefore varies from each other. Therefore, the first step to develop the methodology is to enlarge the data-based library by adding more function-oriented equipment, as a result, the capability of the intelligent library would be improved as more missions can be defined in the functionality confirmation phase.

Product platform is a new concept for ship industry, and it divided the ship product into 'mission' part and 'platform' part. few functionality-related equipment locates in the 'platform' part, whereas most are gathering in the 'mission' area, which, is then become the research field of this study. In fact, the equipment in the 'platform' part also affects the performance of the vessel, it is therefore advised to consider to make further partition inside the 'platform' part, and combine the equipment installable part with the 'mission' part to generate the equipment arrangement design solution.

Simulation

Some developments could also be done in relation to the simulation. First is the improvement of equipment location. Equipment substituted by different kinds of blocks has predetermined location for each type of mission, and this makes some equipment have overlap regarding to the locations. The overlap issue has been solved by DSM in this study, whereas on the other hand the flexibility of the equipment arrangement becomes more narrow. Therefore, which would be negative to the feasibility of the intelligent library. Therefore, instead of fixing the location of each equipment, the emphasis should be focused on the boundary definition of each equipment.

The combination of the web-based APP and Siemens-NX might be another interesting subject with regard to improve the performance of the intelligent library. On the basis of mission definition, corresponding equipment would then be applied in each alternative arrangement design solutions, further, the web-based APP would sketch the general view about the layout. However, these sketches always come with a long description in relation to some issues cannot be recognized in the 2D drawings. Thus, if the combination of the web-based APP with Siemens-NX is made in the intelligent library, corresponding virtual 3D arrangements could also be provided by then, which can not only omit the long descriptions, but a clearer view regarding to the arrangement solutions can also be generated, and this accords with the characteristic of the intelligent library.

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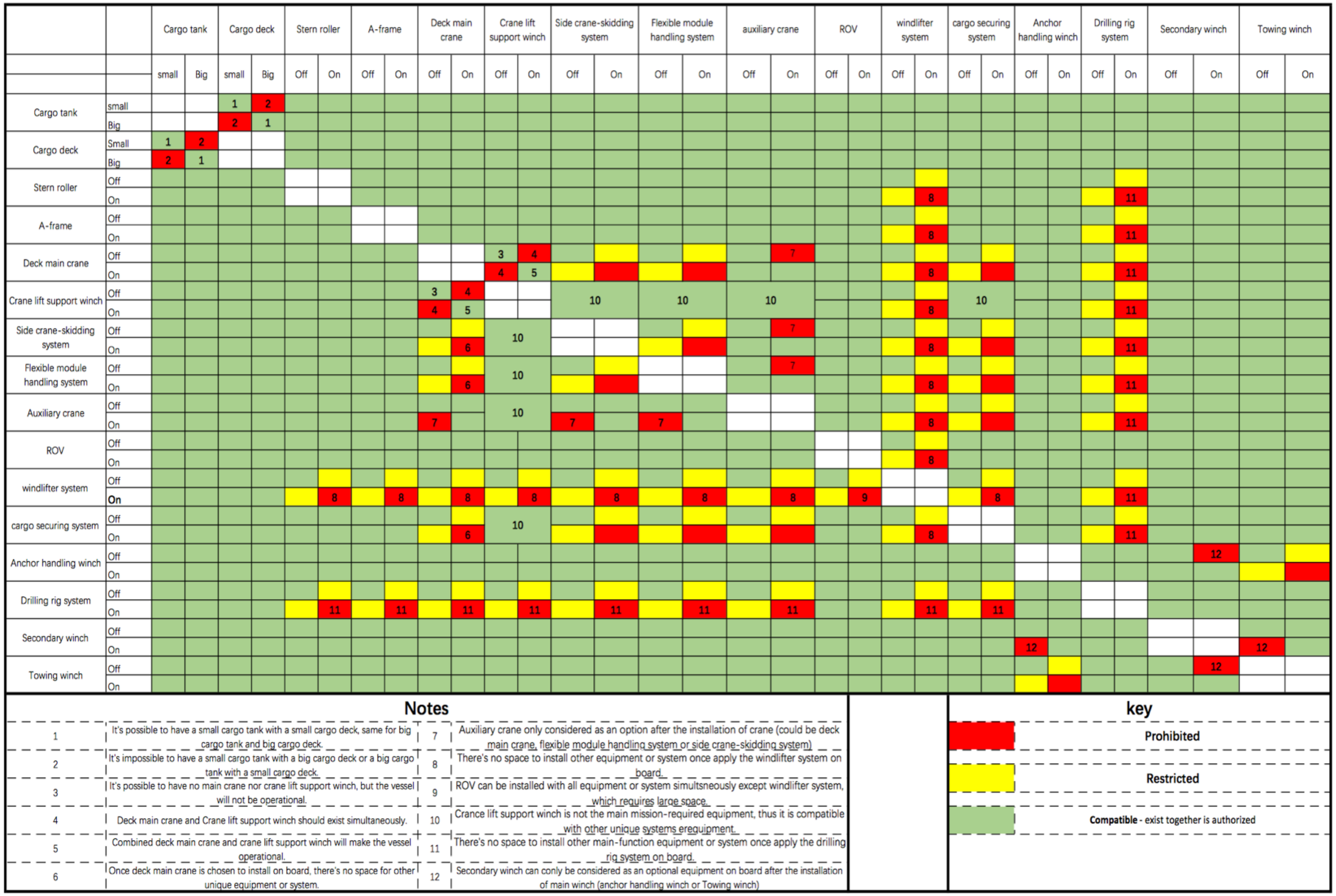
Appendix I - Equipment Compatibility Matrix



		Cargo tank		Cargo deck		Stern roller		A-frame		Deck main crane		Crane lift support winch		Side crane-skidding system		Flexible module handling system		auxiliary crane		ROV		windlifter system		cargo securing system		Anchor handling winch		Drilling rig system		Secondary winch		Towing winch	
		small	Big	small	Big	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On
Cargo tank	small			🟩 1	🟥 2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Big			🟥 2	🟩 1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Cargo deck	Small	🟩 1	🟥 2			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Big	🟥 2	🟩 1			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Stern roller	Off	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥 8	🟩	🟩	🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
A-frame	Off	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥 8	🟩	🟩	🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
Deck main crane	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩 3	🟥 4	🟩	🟨	🟩	🟨	🟩	🟥 7	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟥 4	🟩 5	🟨	🟥	🟨	🟥	🟩	🟩	🟩	🟩	🟨	🟥 8	🟨	🟥	🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
Crane lift support winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩 3	🟥 4			🟩 10	🟩	🟩 10	🟩	🟩 10	🟩	🟩	🟩	🟩	🟨	🟩 10	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥 4	🟩 5			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥 8	🟩	🟩	🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
Side crane-skidding system	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩 10	🟩			🟩	🟨	🟩	🟥 7	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥 6	🟩	🟩			🟨	🟥	🟩	🟩	🟩	🟩	🟨	🟥 8	🟨	🟥	🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
Flexible module handling system	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩 10	🟩	🟩	🟨			🟩	🟥 7	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥 6	🟩	🟩	🟨	🟥			🟩	🟩	🟩	🟩	🟨	🟥 8	🟨	🟥	🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
Auxiliary crane	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩 10	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥 7	🟩	🟩	🟩	🟥 7	🟩	🟥 7	🟩			🟩	🟩	🟨	🟥 8	🟨	🟥	🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
ROV	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟨	🟥 8	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
windlifter system	Off	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨			🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟨	🟥 8	🟨	🟥 8	🟨	🟥 8	🟨	🟥 8	🟨	🟥 8	🟨	🟥 8	🟨	🟥 8	🟨	🟥 9			🟨	🟥 8	🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
cargo securing system	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩 10	🟩	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟩	🟩	🟨			🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥 6	🟩	🟩	🟨	🟥	🟨	🟥	🟨	🟥	🟩	🟩	🟨	🟥 8			🟩	🟩	🟨	🟥 11	🟩	🟩	🟩	🟩
Anchor handling winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟥 12	🟩	🟨
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟨	🟥
Drilling rig system	Off	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟩			🟩	🟩	🟩	🟩
	On	🟩	🟩	🟩	🟩	🟨	🟥 11	🟨	🟥 11	🟨	🟥 11	🟨	🟥 11	🟨	🟥 11	🟨	🟥 11	🟨	🟥 11	🟩	🟩	🟨	🟥 11	🟨	🟥 11	🟩	🟩			🟩	🟩	🟩	🟩
Secondary winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥 12	🟩	🟩	🟩			🟥 12	🟩
Towing winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟥 12		
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥	🟩	🟩	🟩	🟩		

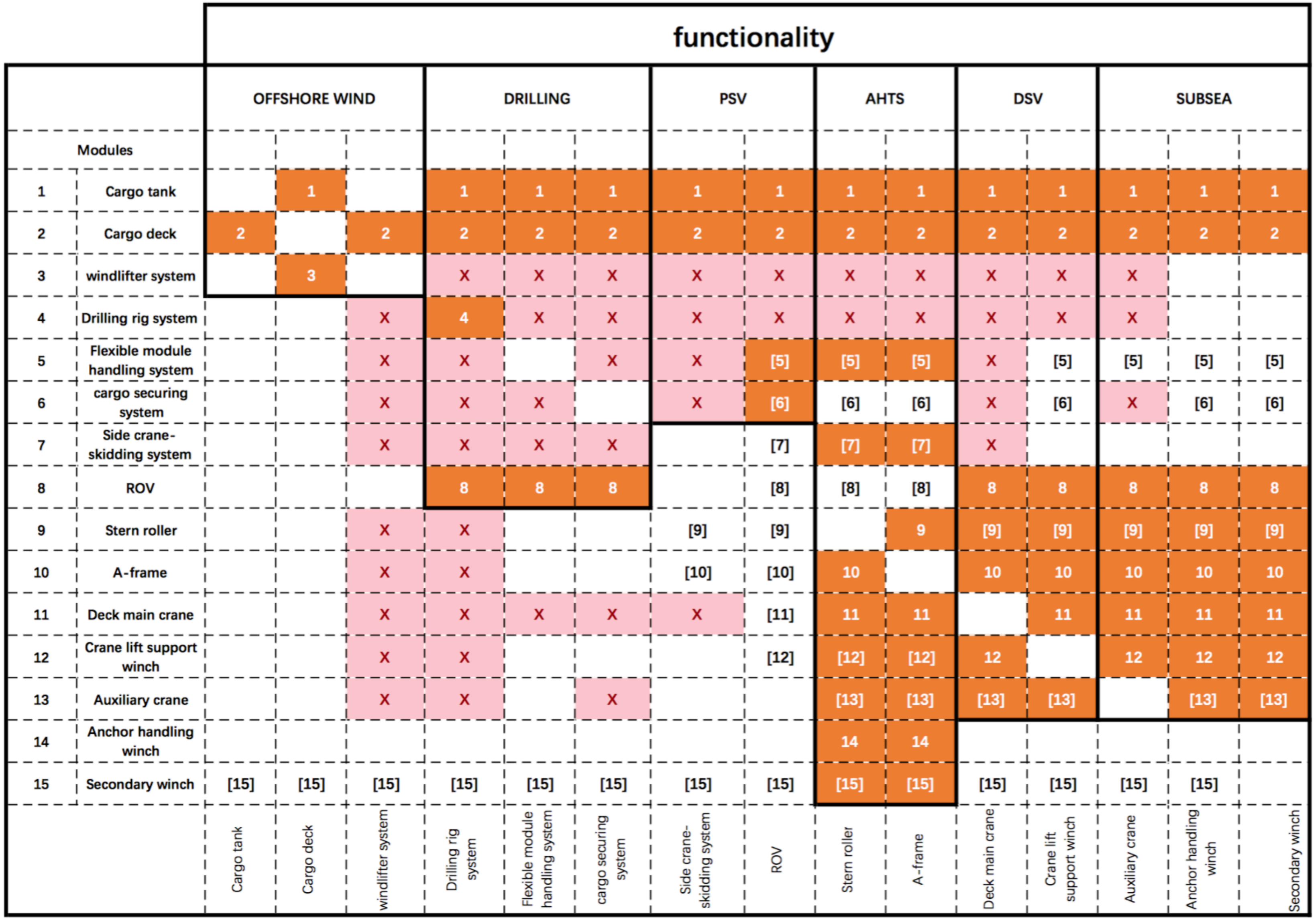
Notes

1	It's possible to have a small cargo tank with a small cargo deck, same for big cargo tank and big cargo deck.	7	Auxiliary crane only considered as an option after the installation of crane (could be deck main crane, flexible module handling system or side crane-skidding system)
2	It's impossible to have a small cargo tank with a big cargo deck or a big cargo tank with a small cargo deck.	8	There's no space to install other equipment or system once apply the windlifter system on board.
3	It's possible to have no main crane nor crane lift support winch, but the vessel will not be operational.	9	ROV can be installed with all equipment or system simultsneously except windlifter system, which requires large space.
4	Deck main crane and Crane lift support winch should exist simultaneously.	10	Crance lift support winch is not the main mission-required equipment, thus it is compatible with other unique systems erequipment.
5	Combined deck main crane and crane lift support winch will make the vessel operational.	11	There's no space to install other main-function equipment or system once apply the drilling rig system on board.
6	Once deck main crane is chosen to install on board, there's no space for other unique equipment or system.	12	Secondary winch can conly be considered as an optional equipment on board after the installation of main winch (anchor handling winch or Towing winch)

key

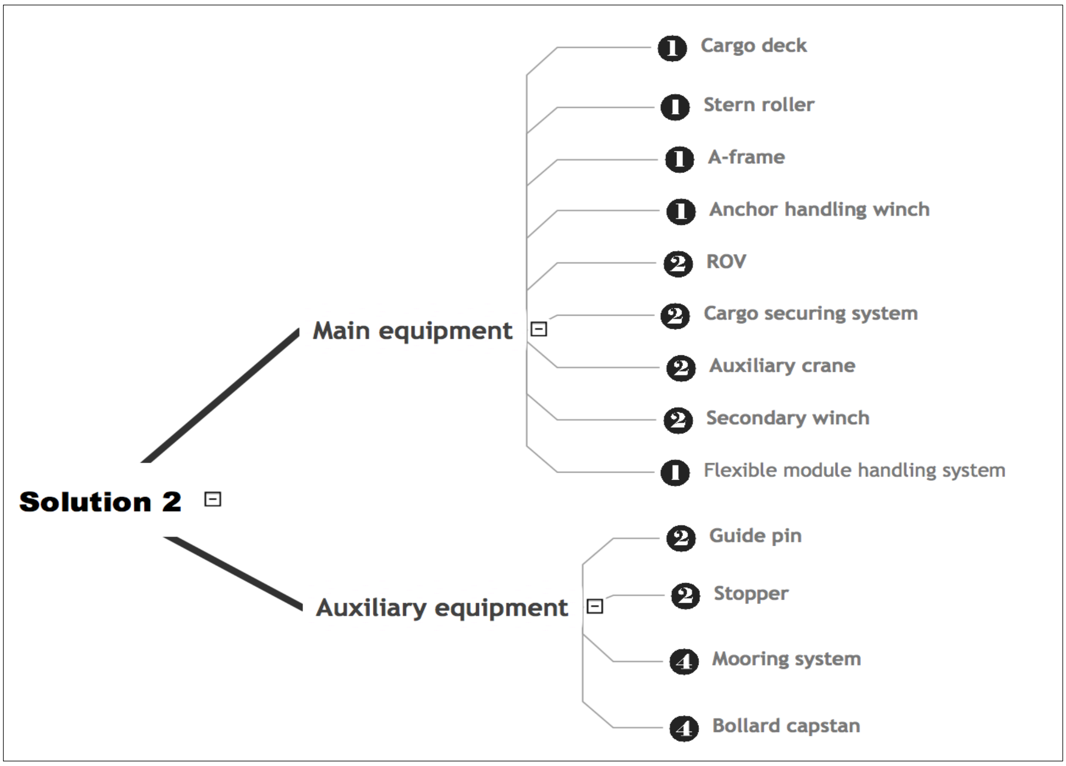
🟥	Prohibited
🟨	Restricted
🟩	**Compatible** - exist together is authorized

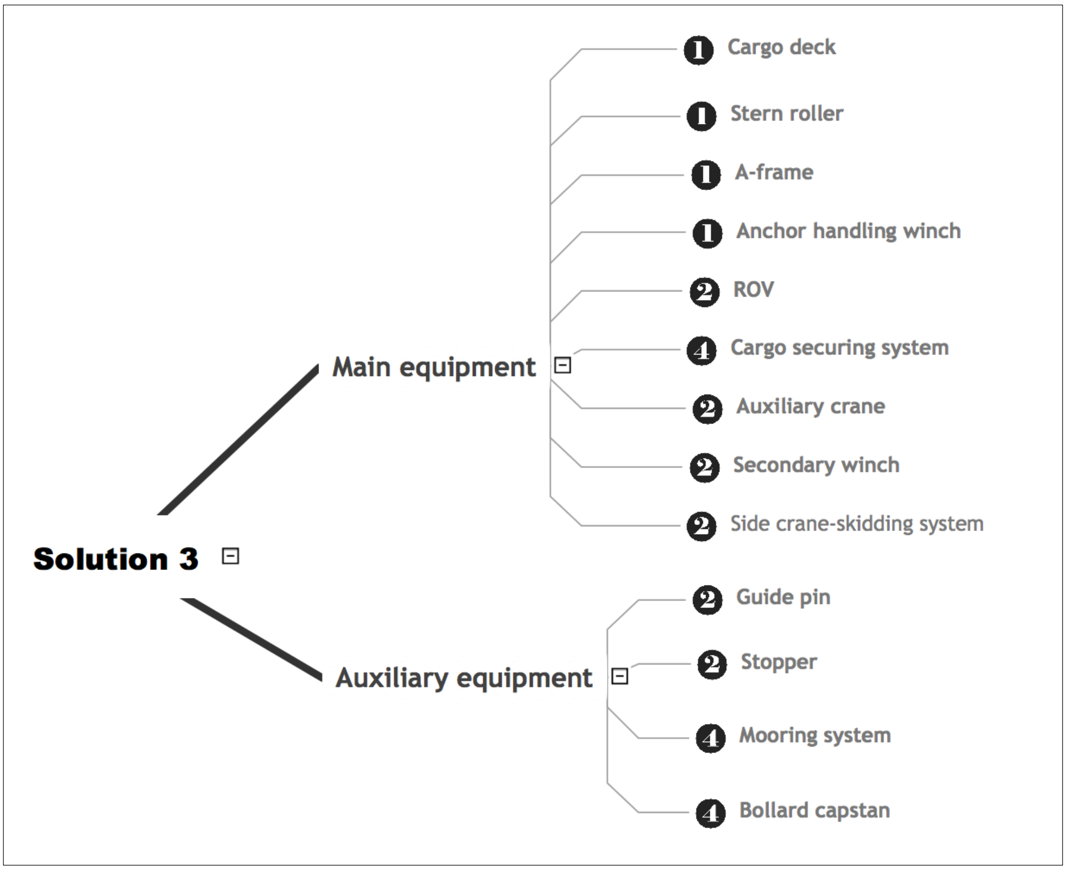
Appendix II – Design Structure Matrix

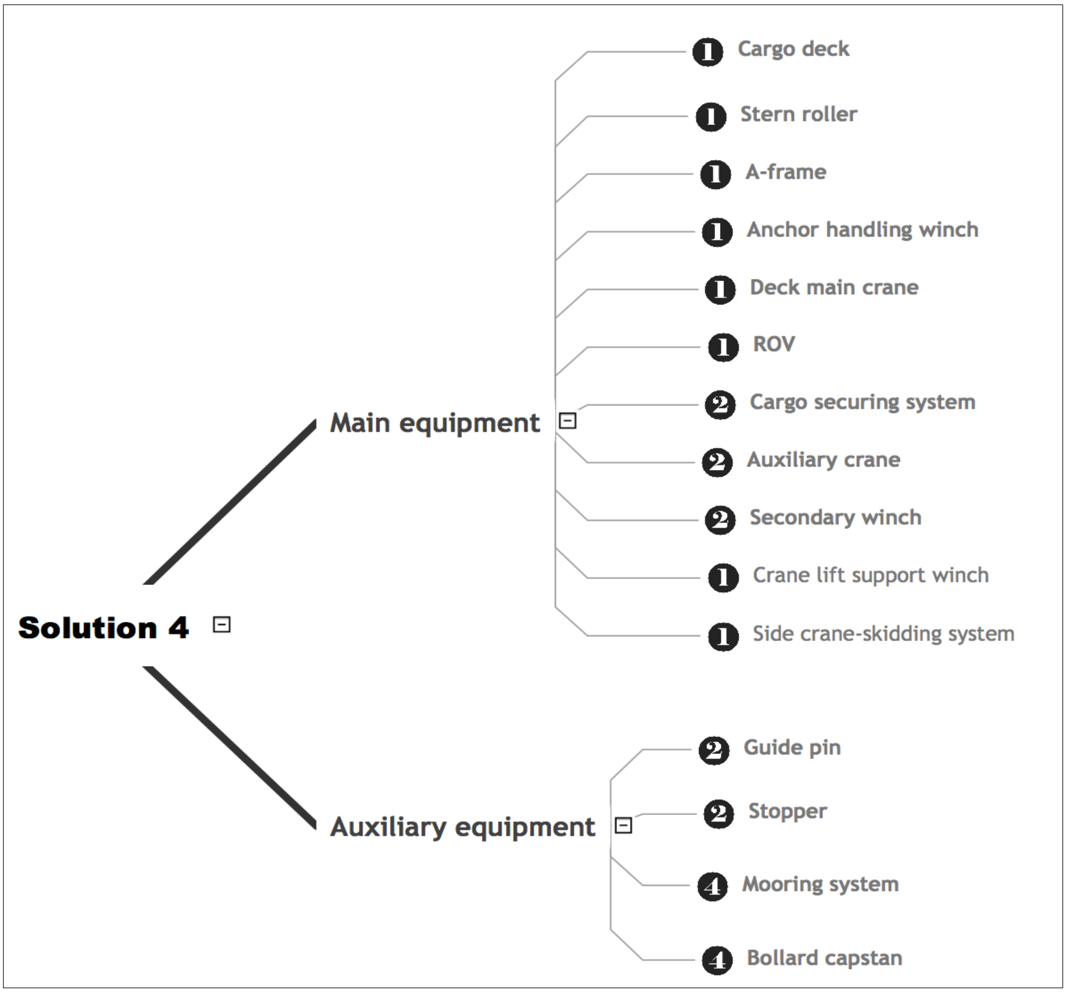


		functionality														
		OFFSHORE WIND			DRILLING			PSV		AHTS		DSV		SUBSEA		
Modules		Cargo tank	Cargo deck	windlifter system	Drilling rig system	Flexible module handling system	cargo securing system	Side crane-skidding system	ROV	Stern roller	A-frame	Deck main crane	Crane lift support winch	Auxiliary crane	Anchor handling winch	Secondary winch
1	Cargo tank		1		1	1	1	1	1	1	1	1	1	1	1	1
2	Cargo deck	2		2	2	2	2	2	2	2	2	2	2	2	2	2
3	windlifter system		3		X	X	X	X	X	X	X	X	X	X		
4	Drilling rig system			X	4	X	X	X	X	X	X	X	X	X		
5	Flexible module handling system			X	X		X	X	[5]	[5]	[5]	X	[5]	[5]	[5]	[5]
6	cargo securing system			X	X	X		X	[6]	[6]	[6]	X	[6]	X	[6]	[6]
7	Side crane-skidding system			X	X	X	X		[7]	[7]	[7]	X				
8	ROV				8	8	8		[8]	[8]	[8]	8	8	8	8	8
9	Stern roller			X	X			[9]	[9]		9	[9]	[9]	[9]	[9]	[9]
10	A-frame			X	X			[10]	[10]	10		10	10	10	10	10
11	Deck main crane			X	X	X	X	X	[11]	11	11		11	11	11	11
12	Crane lift support winch			X	X				[12]	[12]	[12]	12		12	12	12
13	Auxiliary crane			X	X		X			[13]	[13]	[13]	[13]		[13]	[13]
14	Anchor handling winch									14	14					
15	Secondary winch	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]	

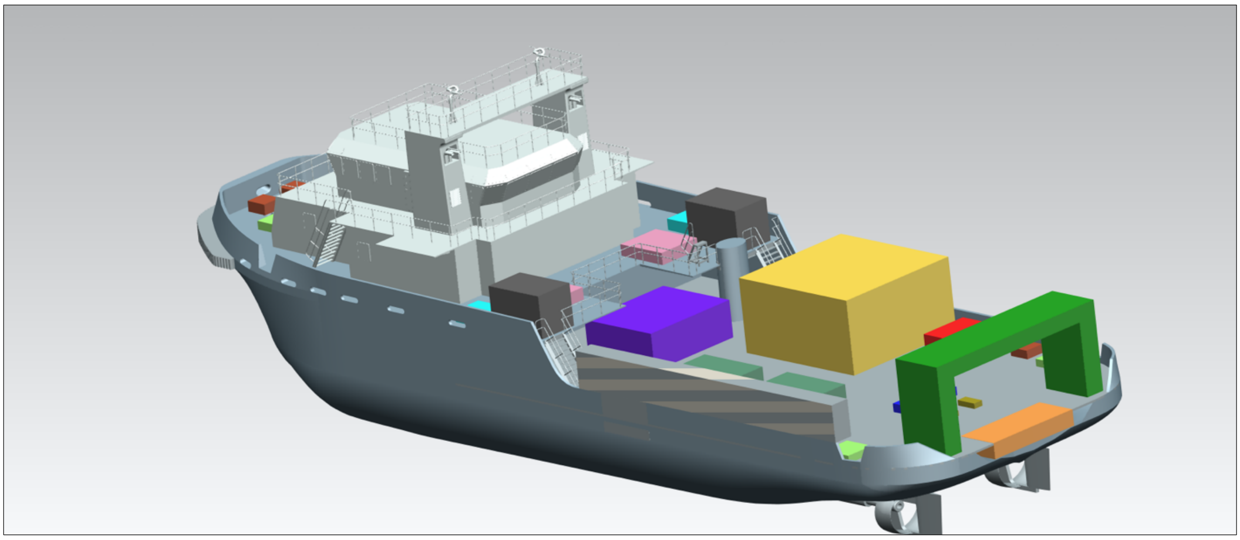
Appendix III – Solution Input Summary

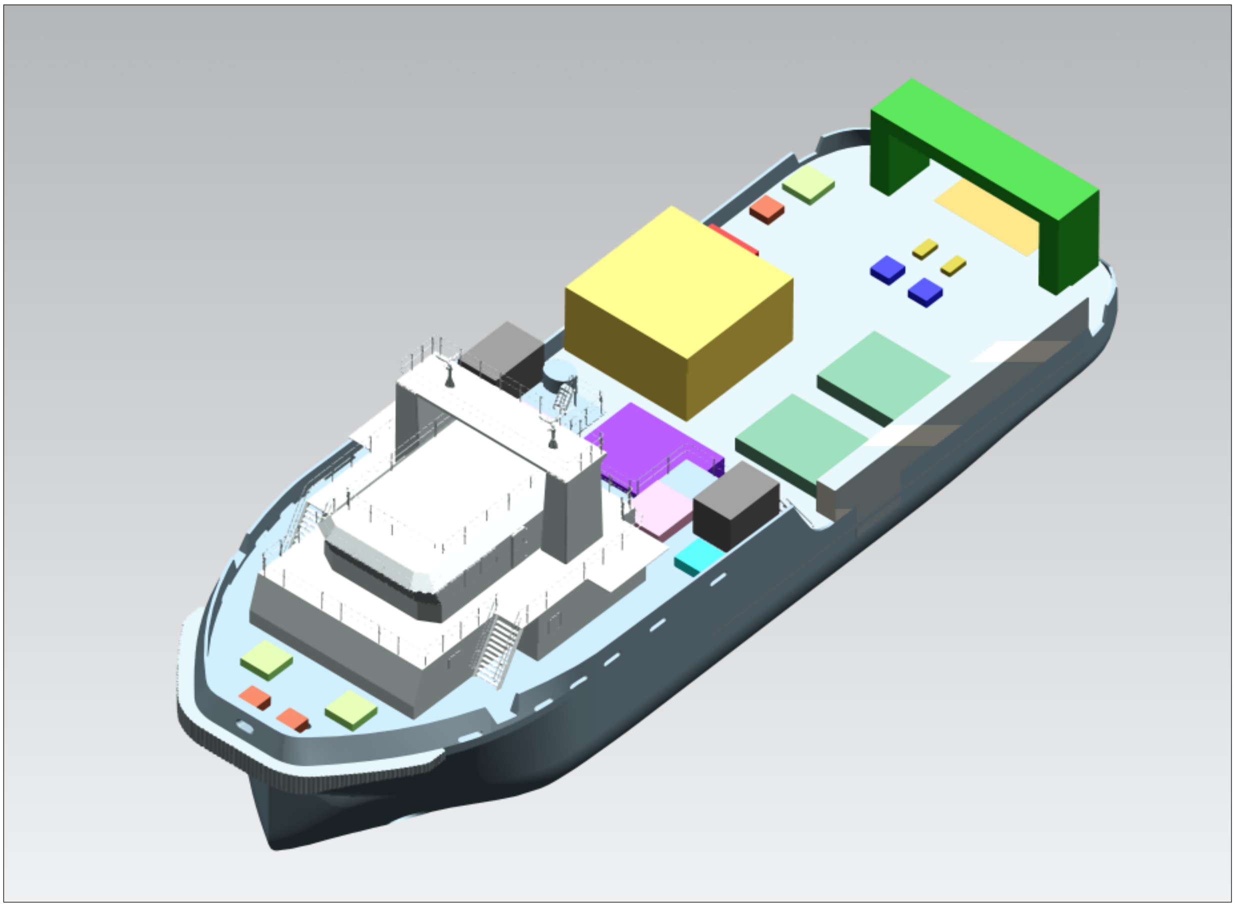





Solution 4
Main equipment
1 Cargo deck
1 Stern roller
1 A-frame
1 Anchor handling winch
1 Deck main crane
1 ROV
2 Cargo securing system
2 Auxiliary crane
2 Secondary winch
1 Crane lift support winch
1 Side crane-skidding system
Auxiliary equipment
2 Guide pin
2 Stopper
4 Mooring system
4 Bollard capstan

Appendix IV – 3D Virtual Arrangement





INTELLIGENT LIBRARY OF OFFSHORE VESSEL EQUIPMENT
—FROM MISSION REQUIREMENTS TO A VIRTUAL VESSEL ARRANGEMENT

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NOTE: this document is in its draft version. text, mathematical model, figures, number of pages and references will be strongly improved by the final paper submission deadline, on April 20th 2016.

KEYWORDS
Intelligent library, Product platform, modulization, virtual arrangement.

ABSTRACT

The purpose of this paper is to design an 'Intelligent Library', based on the deployment of mission requirements to a virtual vessel arrangement via a modular process.

By using the data that stored inside the library, the intelligent library is able to figure out the potential equipment arrangement design solutions according to various mission requirements. Besides, with the help of internal algorithm process, it is possible for intelligent library to determine which design solution is the relatively better.

In order to embody the final arrangement design, A web-based APP and Siemens-NX (software) will also be used in order to present the arrangement in 2D and 3D respectively.

INTRODUCTION

Offshore support vessels (OSV) are specially designed vessels that used for transmitting cargos, persons to the offshore platform and assisting the operations at sea. Basically, the OSV could be divided into several specific types of ships according to different kinds of functions like AHTS (Anchor Handling Tug Supply), PSV (Platform Supply vessel), DSV (Diving Support Intervention Vessel), MPSV (Multi Purpose Supply Vessel) and so on. Normally, the size of these kinds of vessels ranges from 50 m to 110 m in length.

Over the past decade, the demand for OSV increases with a huge rate. A new report from Mordor Intelligence projects that the global offshore support vessel market will grow from $ 39.4 billion in 2014 to $ 69.34 billion by the end of 2020 at a Compound Annual Rate Rate (CAGR) of 9.88 percent. (*Entended coverage from Marine Log's November 2015 Issue*).

The general mission for OSVs is to support and assist the offshore oil and gas exploration and production. This can be decomposed to a lot of different types of specific missions. Normally, a vessel is assigned to do a single mission, whereas it is much more common and competitive for ship designers to generate a ship design solution which makes the vessel achieve two or more mission requirements simultaneously, and this is beneficial for ship owners as well. However, ship owners and designers should reach an agreement on the balance of all mission-solving capabilities in a vessel.

During the process of accomplishing the mission, ship owners would have specific requirements regarding to functionality, vessel dimensions, serving-area and etc., which is supposed to be followed by the ship-builders. For instance, figure 1 indicates 4 potential OSV missions, by adding more specific information like functionality, basic dimensions and some other requirements, they would form the 4 different kinds of missions (PSV; Subsea vessel; AHTS; Offshore wind installation vessel).

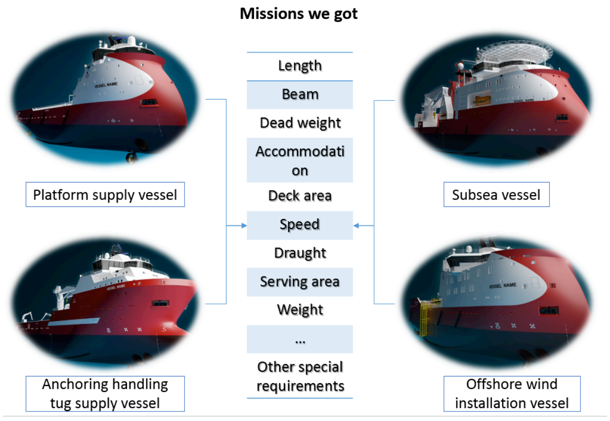


Figure 1: Potential OSV Missions

Figure 2 presents some potential systems and equipment that shipyard may owned, it would then become an interesting subject for arranging these systems according to the various mission requirements rapidly.

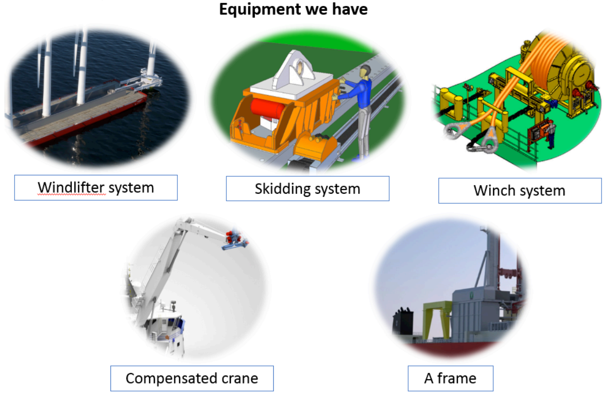


Figure 2: Equipped Systems

To make the equipment arrangement for each mission, a clear understanding about the mission requirement should be analyzed. Then it would come to mind that how to link the mission to the equipment arrangement? And which is the relatively better equipment arrangement design? Further, the Intelligent Library in introduced in order to work as a bond for connecting the mission and equipment-arrangement design, aiming to generate a relatively better equipment arrangement design solution.

FROM MISSION TO VIRTUAL VESSEL ARRANGEMENT

As a shipyard, it may have a variety of OSV orders simultaneously. Like mentioned above, even if all orders are PSV, each one should be regarded as an independent mission because of their own specific mission requirements. After defining the mission, the ship designers are supposed to determine which equipment or system should be installed on board while some would be put aside as an optional part according to the mission. Therefore, it is significant for ship designers to figure out how to link the mission to the equipment arrangement.

Generally, the idea of connecting the mission to the arrangement is to extract the requirements from the mission. Like the conceptual sketch in figure 3 shows, for each mission, it is supposed to have its unique mission requirements, and the 'mission requirement' part would receive the signal both from the 'mission' part and 'arrangement' part, after which the mission-requirement part could send back the information to 'arrangement' part for arranging the installation of equipment and systems for the mission, Also, it would let the 'mission' part knows the arrangement solution satisfy the mission by sending the signal back as well.

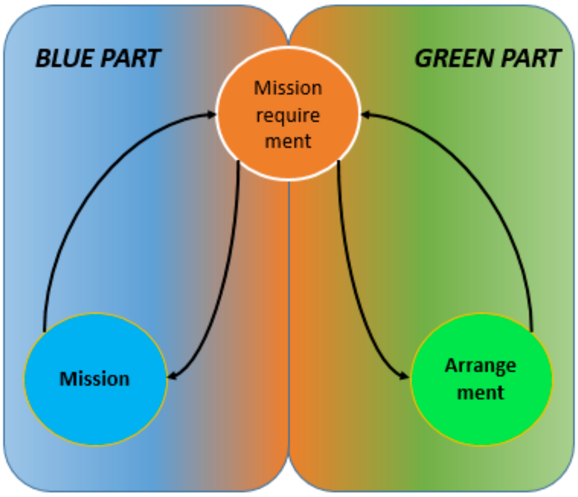
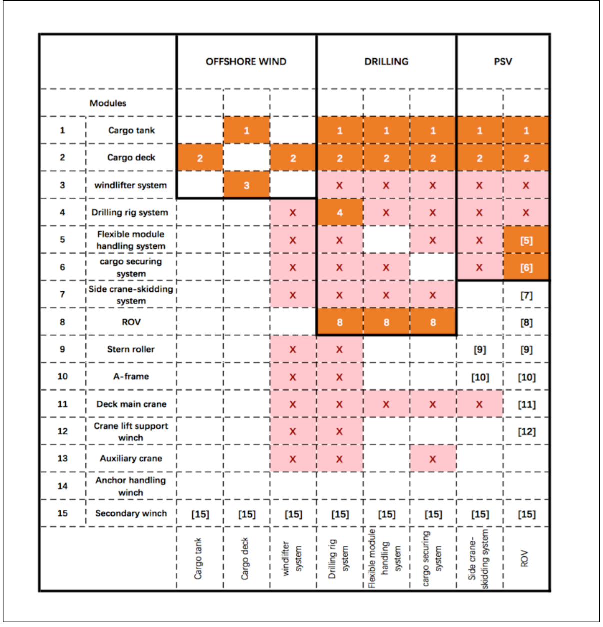


Figure 3: Connection Bond

The connection bond shows in figure 3 can also be divided into 2 parts: blue part and green part. The table 4 below present how the 'mission requirement' part work as a connecting-bond between 'mission' and 'arrangement'.

The interactions between equipment and function are classified in three types: 'required' (orange color marked with number), 'optional' (orange color market with parenthesized number) and 'prohibited'. The equipment marked as 'required' indicates that it is essential to install that equipment in order to operate the given mission such as the relations between 'Drilling rig system' and 'Drilling mission' shown in table 4. If the equipment is marked as 'optional', it means that this equipment is improvement-oriented, which means that the equipment can help to improve the mission performance even though it is not criteria for the mission, therefore, whether to select the 'optional' equipment depends on the ship designers and specific performance requirements. Besides, there's also a kind of relationship which describes only with uncolored parenthesized number, it means that the equipment cannot either develop a function which is required for the mission or help to improve the mission performance, however, with the installation of that equipment, the vessel may develop some spinoff functions.

Table 4: Design Structure Matrix



		OFFSHORE WIND			DRILLING			PSV	
	Modules								
1	Cargo tank		1		1	1	1	1	1
2	Cargo deck	2		2	2	2	2	2	2
3	windlifter system		3		X	X	X	X	X
4	Drilling rig system			X	4	X	X	X	X
5	Flexible module handling system			X	X		X	X	[5]
6	cargo securing system			X	X	X		X	[6]
7	Side crane-skidding system			X	X	X	X		[7]
8	ROV				8	8	8		[8]
9	Stern roller			X	X			[9]	[9]
10	A-frame			X	X			[10]	[10]
11	Deck main crane			X	X	X	X	X	[11]
12	Crane lift support winch			X	X				[12]
13	Auxiliary crane			X	X		X		
14	Anchor handling winch								
15	Secondary winch	[15]	[15]	[15]	[15]	[15]	[15]	[15]	[15]
		Cargo tank	Cargo deck	windlifter system	Drilling rig system	Flexible module handling system	cargo securing system	Side crane-skidding system	ROV

At the time when this solution applied in the real case, it could be soon found out that the alternative arrangement design solution would multiplied over a crowd of mission requirements, which, would make them unmanageable.

VIRTUAL VESSEL ARRANGEMENT

During the process of make arrangement for the mission, one definition should be understood clearly, which, is named as 'Better Arrangement'. In fact, the better arrangement design is fill no more no less all the requirements, which means that it should not only satisfy the mission requirements, but it is also able to find a balance between cost-saving and time-saving.

Based on the web-based APP and Siemens NX, which can help to develop innovative new product. In this project, it is able to arrange the equipment or systems that stored in the computer together to create the possible arrangement design solution instead of making that happened in real life. By using those two method, it's possible to work more quickly and efficiently in the full range of design tasks.

The two 2D sketches below display two different kinds of layout of arrangement design methods, both of them satisfy the mission requirements, the first employs four cargo securing systems as its main equipment while the other one employs both flexible module handling system and cargo securing system. However, the systems that installed on board are a little bit different from each other. This arrangement will be presented by using NX, this sketches here are just for illustrative purpose.

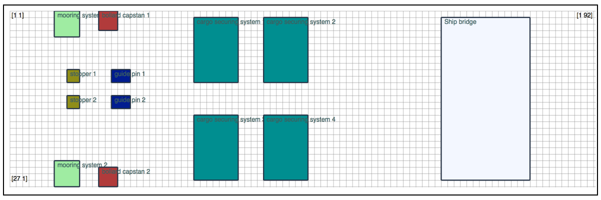


Figure 5: Arrangement Design A

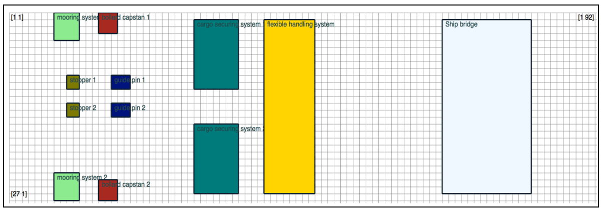


Figure 6: Arrangement Design B

The comparison of equipment-arrangement design solutions is mainly based on the MMRT, as can be seen in table 7. On the basis of MMRT, it would be summarized that both the two main equipment (flexible module handling system and cargo securing system) have a positive effect in performing the PSV mission, whereas solution 2 which install flexible module handling system and cargo securing system simultaneously could better operate the mission.

Table 7 Mission-Module Relationship Table (MMRT)

	OFFSHORE WIND	DRILLING	PSV
Cargo deck	0.6	0.65	0.4
Stern roller	-0.15	-0.15	0.2
A-frame	-0.15	-0.15	0.2
Deck main crane	-0.3	-0.3	0.2
Crane lift support winch	-0.1	-0.1	-0.1
Side crane-skidding system	-0.2	-0.2	0.45
Flexible module handling system	-0.2	-0.2	0.6
Auxiliary crane	0.25	0.15	-0.05
ROV	0.25	0.25	0.05
windlifter system	0.85	-0.3	-0.5
cargo securing system	-0.1	-0.1	0.25
anchor handling winch	0.4	0.4	-0.15
Drilling rig system	-0.45	0.85	-0.5
secondary winch	0.3	0.2	-0.05
sum	1	1	1

INTELLIGENT LIBRARY METHODOLOGY

The process of completing a mission can be divided into four parts: mission, design, arrangement and delivery. Normally, after confirming the specific mission requirements from the ship owner, it takes lots of time for the ship designers to finish all detailed drawings according to the order. Besides, after understanding about the mission requirements, the ship designers may have varied kinds of design solutions that allow a rapid exploration of potential option. However, during the process of designing the suitable solution that is able to satisfy the mission requirements, lots of difficulties would appear from both the complexity of ships and the complexity of the ship design process. [*Timothy P.M. 2010.]* In this case, a system which is called 'Intelligent library' stepped forward for undertaking the intractable problem.

Based on the idea of connecting the mission to the arrangement, the concept behind 'intelligent library' did some extension. Unlike the knowledge presented above, instead of directly connecting the 'mission requirement' part with 'arrangement' part, there are one more main module in this conceptual sketch, which, is 'Intelligent library' (as shown in figure 8). Basically, the idea of the function of the library is more like a smart automatic assembly tool. At the time when the designer is told which kind of vessel is going to be built and tells the library, this library would perceive which equipment should be equipped in the vessel as a mandatory part while some equipment would be there as an option.

In order to operate the 'intelligent library' swimmingly, some preconditions should be defined. Since the library is going to work as a connection bond between 'mission' and 'arrangement', enough data (equipment and systems) should be stored inside so that it could pick up the useful components according to the mission. In addition, in the connection between 'intelligent library' and 'arrangement', there exists one more section that is named as 'smart algorithm', actually, it is one of the most significant part in the library to make it work in an intelligent way. Like mentioned before, the alternative arrangement design solution would multiply over a crowd of mission requirements without making any filtration. By having the 'smart algorithm', it would help to filter the unnecessary design solution and make the remaining 'arrangement' solution as smart as possible.

The flow chart is shown in figure 8, starting from the 'mission' part, the 'mission requirement' would then able to extract the key requirements from it and send them to the 'Intelligent library'. By using the smart algorithm, the library would then pick up the better design solution to make the arrangement, at the same time, the signal of the design-decision would be received by the 'mission requirement', where it is then able to check if it satisfy the mission. At last, the 'arrangement' would send the design-method signal to 'mission' part, which works as a double-check.

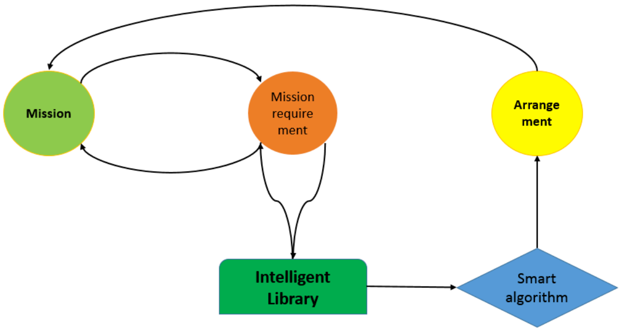


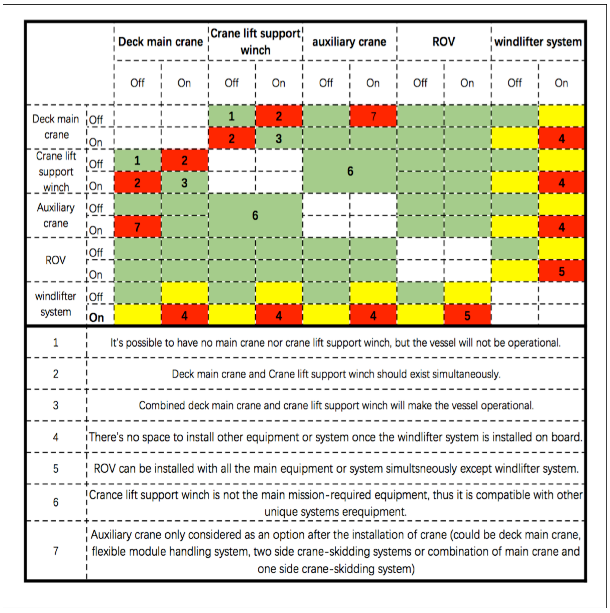
Figure 8: Conceptual Sketch Of Intelligent Library

Design structure matrix (DSM) can be used to organize product development tasks to minimize unnecessary design iterations, also, it is able to increase the efficiency of the design process. A DSM consisting of parts or components can be defined as an architectural DSM, where the requirements, missions and equipment are placed either on the row or in the columns of the matrix and interactions between them are mapped (*Hölttä – Otto, 2005*).

The interactions between equipment are specific analyzed and described through compatibility matrix, which is defined as the ability of two different equipment of different versions to interoperate. Possibilities of potential configuration arrangement solutions could be further studied with the help of equipment compatibility matrix.

The equipment-compatibility matrix mainly contains the equipment that could either develop a new function for the vessel or improve the present performance. The primary objective of employing the equipment-compatibility matrix is because some equipment's locations may have overlaps with each other, also, it is pointless to install two different equipment that could develop the same function. Therefore, for the auxiliary equipment such as guide pin or stopper, their relations with main equipment would not be studied as they are common and have no collision with the main mission-related equipment.

In the matrix, equipment is listed both in the column and row, relationships between equipment are classified as compatible (marked as 'green') and incompatible (marked as 'red'). The relationships between two equipment marked as 'yellow' represent that they are compatible but restricted. Last but not least, some special statements regarding to the interactions between equipment would also presented through the compatibility matrix.



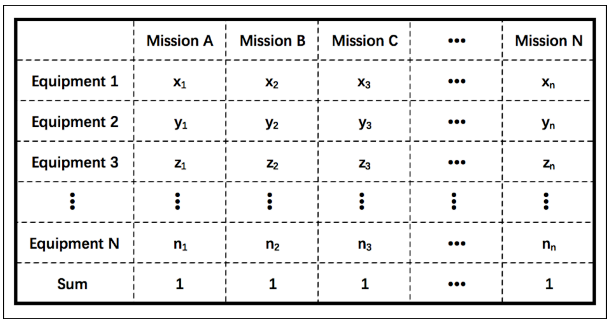
		Deck main crane		Crane lift support winch		auxiliary crane		ROV		windlifter system	
		Off	On	Off	On	Off	On	Off	On	Off	On
Deck main crane	Off			🟩 1	🟥 2	🟩	🟥 7	🟩	🟩	🟩	🟨
	On			🟥 2	🟩 3	🟩	🟩	🟩	🟩	🟨	🟥 4
Crane lift support winch	Off	🟩 1	🟥 2			🟩 6	🟩	🟩	🟩	🟩	🟨
	On	🟥 2	🟩 3			🟩	🟩	🟩	🟩	🟨	🟥 4
Auxiliary crane	Off	🟩	🟩	🟩 6	🟩			🟩	🟩	🟩	🟨
	On	🟥 7	🟩	🟩	🟩			🟩	🟩	🟨	🟥 4
ROV	Off	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟨
	On	🟩	🟩	🟩	🟩	🟩	🟩			🟨	🟥 5
windlifter system	Off	🟩	🟨	🟩	🟨	🟩	🟨	🟩	🟨		
	On	🟨	🟥 4	🟨	🟥 4	🟨	🟥 4	🟨	🟥 5		

1	It's possible to have no main crane nor crane lift support winch, but the vessel will not be operational.
2	Deck main crane and Crane lift support winch should exist simultaneously.
3	Combined deck main crane and crane lift support winch will make the vessel operational.
4	There's no space to install other equipment or system once the windlifter system is installed on board.
5	ROV can be installed with all the main equipment or system simultsneously except windlifter system.
6	Crance lift support winch is not the main mission-required equipment, thus it is compatible with other unique systems erequipment.
7	Auxiliary crane only considered as an option after the installation of crane (could be deck main crane, flexible module handling system, two side crane-skidding systems or combination of main crane and one side crane-skidding system)

Figure 9 Equipment Compatibility Matrix

The objective of assemblies is not just to make the equipment arrangement, but assemble the most suitable equipment for performing a given mission, and the presented design solution should also satisfy the mission requirement, this is the right vessel for the right mission.

The main principle of the intelligent library is to follow requirements regarding to the functionality and performance settled by the customers, and further the suitable equipment would be organized and assembled and compared by in order to present the better arrangement. Mission-Modules Relationship Table (MMRT) is presented here and will be further applied in the study in order to make comparison for each potential arrangement solution. This table specifically describes how essential one equipment is in order to operate the given mission by grading 'equivalent' credit. The credit varies from -1 to 1, for the equipment which is highly required according to the mission requirements, it would capture a high positive score, however, low negative score would be marked if the equipment is viewed as a useless tool or its action is counterproductive for achieving the wanted performance.



	Mission A	Mission B	Mission C	•••	Mission N
Equipment 1	x_1	x_2	x_3	•••	x_n
Equipment 2	y_1	y_2	y_3	•••	y_n
Equipment 3	z_1	z_2	z_3	•••	z_n
⋮	⋮	⋮	⋮	⋮	⋮
Equipment N	n_1	n_2	n_3	•••	n_n
Sum	1	1	1	•••	1

Figure 10 Mission-Module Relationship Table (MMRT)

CASE STUDY — APPLY THE INTELLIGENT LIBRARY TO AHTS

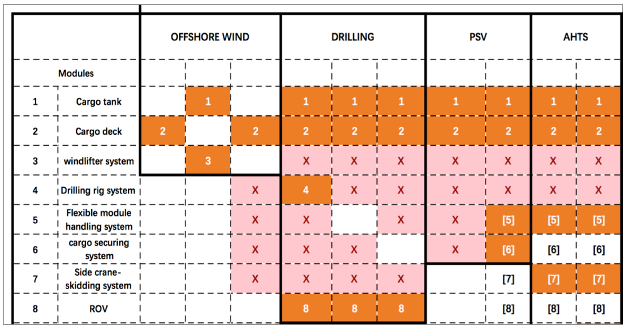
As one of the most important type of OSV vessel, AHTS vessel has its characteristic design methodology. Normally, AHTS performs the role of assisting offshore installation with the anchor handling operation (Wennersberg, 2009). The primary mission of the big OSV vessel case is anchor handling tug supply, and the vessel is intended to perform several potential roles simultaneously by equipping a set of alternative versatile equipment. By comparing these different kinds of alternative arrangement-solutions, a better design method could be stand out in order to satisfy the customer's requirements as better as possible.

AHTS is mainly used to perform the towing operation and anchor handling supply for deployment. In order to have a better understanding about how the main equipment should be organized, the DSM would be applied here, from which we could see the filter the alternative essential main equipment.

The creation of main equipment list is based on the specificity of vessel equipment functionality, which means that each equipment inside could bring about a new function that cannot replace by others. Therefore, we can obtain as following:

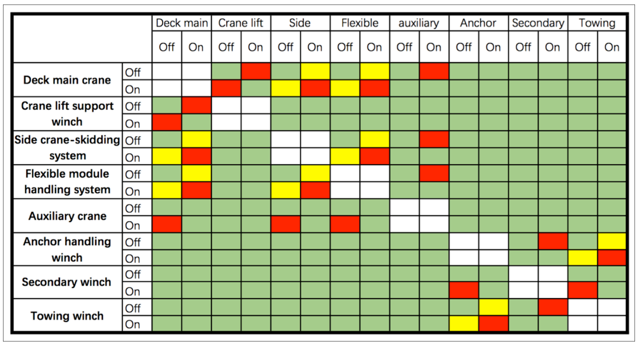
Essential equipment: cargo deck, stern roller, A-frame, crane and anchor handling winch.

Optional equipment: cargo securing system, ROV, crane lift support winch, auxiliary crane and secondary winch.



		OFFSHORE WIND			DRILLING			PSV		AHTS	
	Modules										
1	Cargo tank		🟧 1		🟧 1	🟧 1	🟧 1	🟧 1	🟧 1	🟧 1	🟧 1
2	Cargo deck	🟧 2		🟧 2	🟧 2	🟧 2	🟧 2	🟧 2	🟧 2	🟧 2	🟧 2
3	windlifter system		🟧 3		X	X	X	X	X	X	X
4	Drilling rig system			X	🟧 4	X	X	X	X	X	X
5	Flexible module handling system			X	X		X	X	🟧 [5]	🟧 [5]	🟧 [5]
6	cargo securing system			X	X	X		X	🟧 [6]	[6]	[6]
7	Side crane-skidding system			X	X	X	X		[7]	🟧 [7]	🟧 [7]
8	ROV				🟧 8	🟧 8	🟧 8		[8]	[8]	[8]

Figure 11 Part Of DSM Of AHTS



		Deck main		Crane lift		Side		Flexible		auxiliary		Anchor		Secondary		Towing	
		Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On	Off	On
Deck main crane	Off			🟩	🟥	🟩	🟨	🟩	🟨	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩
	On			🟥	🟩	🟨	🟥	🟨	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Crane lift support winch	Off	🟩	🟥			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	On	🟥	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Side crane-skidding system	Off	🟩	🟨	🟩	🟩			🟩	🟨	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩
	On	🟨	🟥	🟩	🟩			🟨	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Flexible module handling system	Off	🟩	🟨	🟩	🟩	🟩	🟨			🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩
	On	🟨	🟥	🟩	🟩	🟨	🟥			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Auxiliary crane	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩
	On	🟥	🟩	🟩	🟩	🟥	🟩	🟥	🟩			🟩	🟩	🟩	🟩	🟩	🟩
Anchor handling winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟥	🟩	🟨
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟨	🟥
Secondary winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩			🟥	🟩
Towing winch	Off	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟥		
	On	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟥	🟩	🟩		

Figure 12 Part Of Compatibility Matrix Of AHTS

Further, combine the DSM and equipment compatibility matrix, we could propose four equipment arrangement design solutions, and the corresponding arrangement sketch in 2D is shown below.

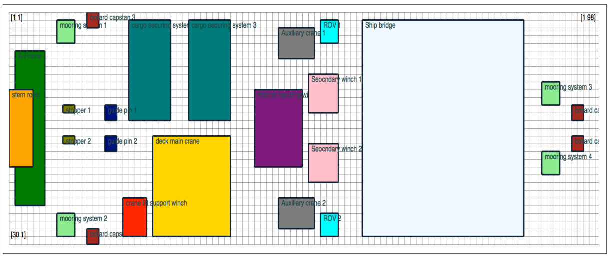


Figure 13 Arrangement Design Solution 1

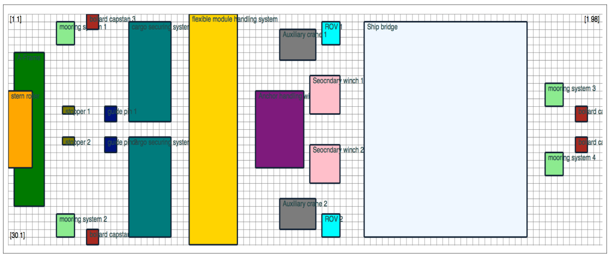


Figure 14 Arrangement Design Solution 2

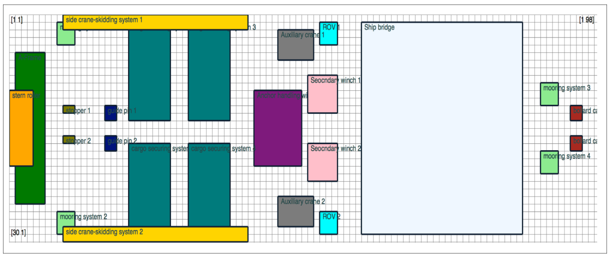


Figure 15 Arrangement Design Solution 3

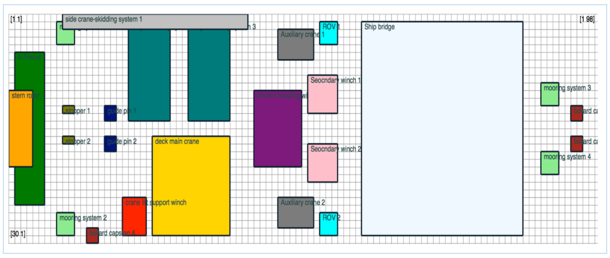
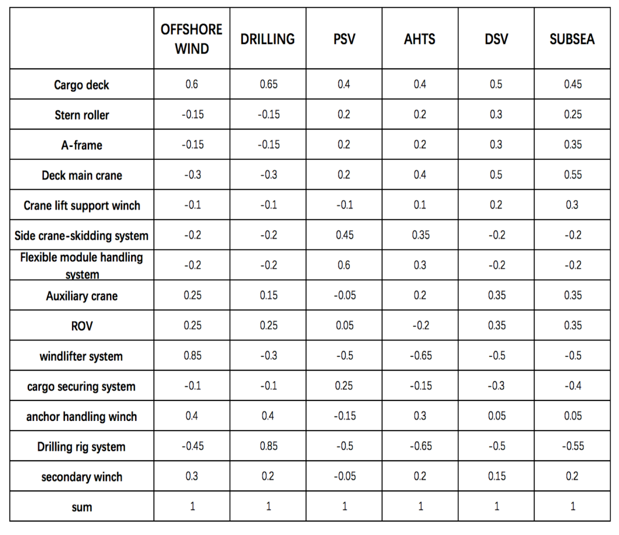


Figure 16 Arrangement Design Solution 4

RESULT

The whole evaluation phase would reply on the Mission-Modules Relationship Table (MMRT), which specifically describes how necessary one equipment is for performing each potential mission by grading 'equivalent' credit. The credit varies from -1 to 1, higher positive score would be given to the equipment which is particularly essential for the given mission, whereas low negative score would be arranged to the equipment which is not beneficial for performing the given mission.

Table 17 MMRT Of AHTS



	OFFSHORE WIND	DRILLING	PSV	AHTS	DSV	SUBSEA
Cargo deck	0.6	0.65	0.4	0.4	0.5	0.45
Stern roller	-0.15	-0.15	0.2	0.2	0.3	0.25
A-frame	-0.15	-0.15	0.2	0.2	0.3	0.35
Deck main crane	-0.3	-0.3	0.2	0.4	0.5	0.55
Crane lift support winch	-0.1	-0.1	-0.1	0.1	0.2	0.3
Side crane-skidding system	-0.2	-0.2	0.45	0.35	-0.2	-0.2
Flexible module handling system	-0.2	-0.2	0.6	0.3	-0.2	-0.2
Auxiliary crane	0.25	0.15	-0.05	0.2	0.35	0.35
ROV	0.25	0.25	0.05	-0.2	0.35	0.35
windlifter system	0.85	-0.3	-0.5	-0.65	-0.5	-0.5
cargo securing system	-0.1	-0.1	0.25	-0.15	-0.3	-0.4
anchor handling winch	0.4	0.4	-0.15	0.3	0.05	0.05
Drilling rig system	-0.45	0.85	-0.5	-0.65	-0.5	-0.55
secondary winch	0.3	0.2	-0.05	0.2	0.15	0.2
sum	1	1	1	1	1	1

Picking up the evaluation of the four solutions in performing spinoff missions, we may notice that solution 3 which owns four cargo securing systems appears to be a better one to operate PSV mission, however, as the main mission that defined in the early stage is AHTS, the attention should be focused in AHTS-based performance. Therefore, the arrangement which employs both deck main crane and side crane-skidding system is evaluated to be a better equipment-arrangement design solution for performing the AHTS mission in the big case.

The core idea of 3D arrangement method is based on the concept of module design and carried out by Siemens-NX. A common scalable platform is constructed by means of the idea of product platform, different kinds of equipment can be further configured here to compose diverse arrangement-design solutions.

As the 4th solution is evaluated as the better arrangement design solution for AHTS after the comparison made in the previous phase, therefore the corresponding 3D arrangement layout would be simulated with the help of Siemens-NX in this stage. The general view of 4th solution is shown in Figure 18, equipment employed in this design is substituted by several blocks of various sizes based on the dimension of each equipment.

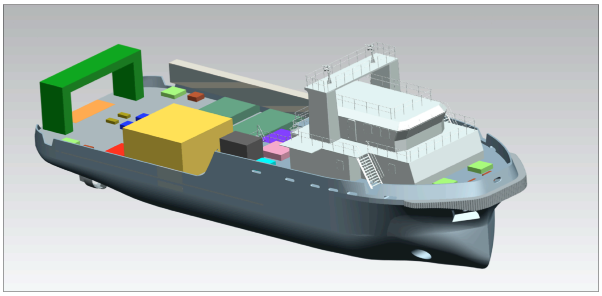


Figure 18 3D virtual arrangement

CONCLUSION

The methodology developed inside the intelligent library aims to generate the better arrangement design solution for one of the specific given mission based on a certain number of equipment stored in the data-based library. The employment of DSM assists to classify the relations between alternative equipment and defined mission into four categories: essential, potential, dispensable and dangerous. Further, the equipment compatibility matrix gives a great overview about the possibility of the installation of two equipment, which, is a critical reference indication. Last but not least, as the cornerstone of evaluation phase, the MMRT specifically describes the dependency level of one equipment to a mission, aiming to reveals the relatively better design solutions among the alternative choices, which, is as proposed to be the final achievement of the intelligent library. However, the creations of MMRT is much more flexible, which indicates that the dependency degree for one equipment to a mission varies from ship designers to ship designers. Therefore, it would be convinced once MMRT can be developed to be a criterion for evaluation.

The case study describes in specific how the methodology is applied in a real case—AHTS, along with the feedback of the feasibility of the methodology. The case shows that a better arrangement design solution could be able to generated step-by-step following the process algorithm. The reason for defining the AHTS as luxury edition is because of the cost issue, which is confidential and hard to collect the relevant data. In fact, the cost of each arrangement design solution can be considered as a vital factor when making comparisons between alternative arrangement design solutions. In spite of some deficiencies and limitations, it is still a good start to attempt the intelligent library in ship industry, and through both the employment of advanced concepts and methods, we could realize that the whole process is better-arrangement-oriented, which, is exactly the proposed objective of constructing the intelligent library.

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