A Study on Modularization and Arrangement of Ship Piping System in Consideration of Series Ships

（シリーズ船を考慮した船舶配管システムのモジュール化と配置設計に関する研究）

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DISSERTATION

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Abstract

Presently, the market competition in the ship building industry has become exceedingly intense, and to compete in the global market, shipbuilders are required to produce ships that are more efficient and constructed in relatively short turnaround times-periods between order placement and delivery. This necessitates the development of new methods such as building series ships, design optimization, and modularization concepts. This study presents a design optimization approach based on the modularization concept for engine room design. The characteristics of the proposed method are as follows: piping systems, employed in multiple bulk carrier series ships, of different sizes are focused on. The cost and weight of these systems and the similarity and common features of the concerned modules and arrangements are considered. The piping system design process is divided into two stages—module definition and arrangement design. A design structure matrix (DSM) has been adopted to define an effective module that could be employed for designing various series ships. In the arrangement design stage, an optimization system has been developed using a genetic algorithm to obtain a similar pattern for module arrangement in various series ships with specific considerations extended toward cost and similarity. The details of the proposed method are discussed in this study. In addition, the paper discusses the piping-system design of an actual ship by using the proposed method, and its effectiveness has been evaluated.

Keywords: piping system; modularization; arrangement; design optimization; DSM

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Chapter 1

Introduction

1.1 Present Situation of Ship Piping Design

In the shipbuilding industry, continues improvements in production methods in order to achieve higher values of design efficiency. Various production concepts, such as block division, modularization, and shipbuilding with a standard design are possible solutions for achieving improved production capability. Typically, the initial design of an engine room is performed based on advance design data, such as reference ship data, design constraints, and theoretical optimum solutions.

Piping design as a part of the shipbuilding process is complex and labour-intensive due to significant physical and operational constraints and the crucial influence on outfitting construction productivity. Consequently, improvement in piping design operations and processes has always been one of the most important goals in shipbuilding. In applications such as shipbuilding, the individual designs of the piping system inside an engine room and their specifications and arrangement differ significantly from one ship to another owing to differences in ship sizes. Consequently, the total time design and cost production increased rapidly.

Nowadays, series ships concept is adopted in Japanese shipyards. In the series ship, the hull structure and lines are same. Therefore, we can take the merit of series ship, that is, design time reduction, cost reduction, quality improvement and reduction of mistakes. However, the piping system is different for each ships due to the differences of the owner requirements. Therefore, piping system is designed and constructed one by one. It reads to the increase of total cost, increase of the mistakes and drop-off in the quality. In a word, a present piping design aims at the local optimization.

1.2 Modularization and its Application in Automobile Industry

Considering the above-mentioned characteristics of piping system design in shipbuilding applications, it is important for shipbuilders to develop a method based on standard modularization while also considering the different sizes of the vessels in a series of ships. In addition, the development of a standard modular arrangement is important in terms of achieving overall design optimization.

The view regarding modularization is gradually changing, and nowadays, the modularization concept is being employed in relation to the overall optimization of vehicles in the automobile industry. Consider the example of Nissan Motors' Common Module Family, which is a modular architecture concept that can be applied to a variety of different vehicles. As such, it enables the efficient design and manufacture of models such as small cars, sedans, and SUVs, simply by altering the combination of engine compartment, cockpit, and front and rear underbodies as modular units. The adoption of this type of approach to modularization provides an opportunity to enhance the design of piping system in engine rooms.

1.3 Objective of this Study

Based on the above considerations, we have been developing the system to optimize the engine room of various series ships based on the modularization concept.

Followings are the objectives of this study:

- Modularization of piping design inconsideration of various series ships.
- Optimization of piping system arrangement in engine room in consideration of various series ships.

In order to realize the objectives, there are two important points, module design and arrangement design. In the module design, common modules for various series ships are required. Furthermore, in the arrangement design, optimized arrangement by considering the similarity and cost minimization is required. The basic concepts of proposed methods and details of information processing are described in this study. Moreover, the effectiveness of the modularization and arrangement methods in piping system are discussed in consideration of various series ships.

1.4 Organization of this Dissertation

The structure of this thesis is presented in Fig.1.1. Summary of each chapter is shown in the followings.

(Chapter 1) In the beginning of this thesis a short overview of recent engine room design including piping system in shipbuilding industry is described. In this chapter, modularization concept and arrangement optimization of piping design is introduced. Furthermore, the objective and scope of the study are clarified.

(Chapter 2) In this chapter, the related studies of ship piping system is described. Some references about the study of ship piping design, modularization concept, modularization using DSM and automatic arrangement are described. Furthermore, the characteristics of this study is clarified. In addition, the differences of this study compare to the related studies is described.

(Chapter 3) The basic concept to optimize the piping design is introduced and discussed. This chapter consists of three important points, such as: problem definition, module definition and arrangement definition.

(Chapter 4) Modularization using design structure matrix (DSM) is defined and illustrated. Flow of modularization in consideration of series ships to obtain common module is discussed and example problems are solved. Furthermore, the evaluation of modularization result is described.

(Chapter 5) Optimization of module arrangement in consideration various series ships is defined and illustrated. A genetic algorithm was adopted for the sake of optimization. Therefore, the cost of pipes and similarity of arrangements were set as objective functions.

(Chapter 6) A discussion about the complete system for the optimization of module arrangement in consideration of various series ships is presented. To evaluate the effectiveness of this proposed method, several cases were performed. Therefore, the cost comparison and arrangement comparison are the important points to be discussed.

(Chapter 7) The last chapter presents the conclusions of the study and future tasks.

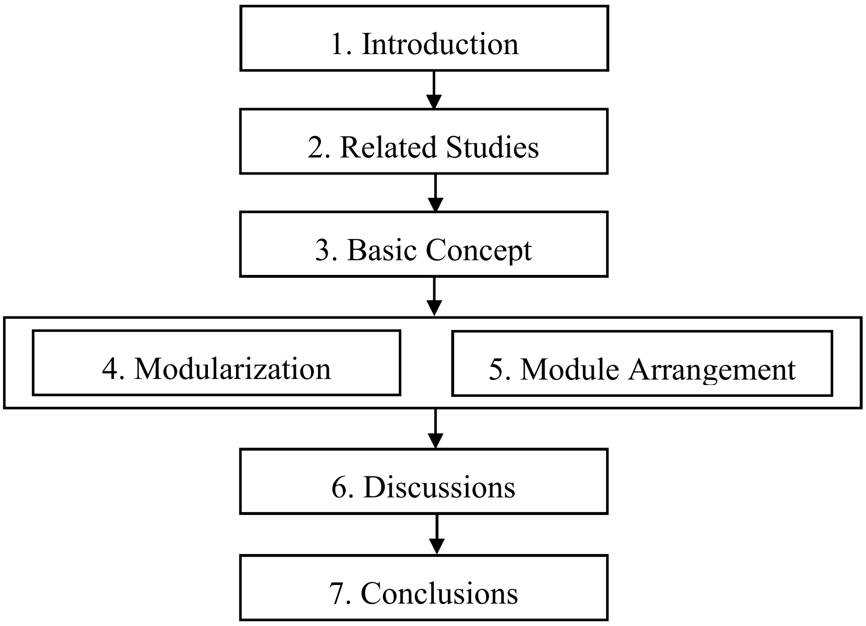


Fig. 1.1 Structure of the dissertation

Chapter 2

Related Studies

2.1 Studies on Modularization

2.1.1 Definition of module and modularization

During the last 20 years, many industries have moved from designing individual, “one-of-a-kind” products, towards developing product platforms from which a large number of variants or customized products can be configured. There are numerous cases from diverse industries on how this technology has improved the product development process [Simpson 2003]. For instance, Volkswagen has applied platform technology across their Audi, Volkswagen, Seat and Skoda brands. Black & Decker has developed a common platform with extensive component reuse both across different brands and across different product types. Sony developed a platform on which they developed and delivered a stream of Walkmans models over many years. The benefits reported are reduced cost, shorter development cycles and the ability to maintain a broad product range while standardizing and reducing the number of different components and configuration elements [Wuuren and Halman 2001].

Modularization is related to product platforms in terms of being the building blocks from which the product platform is built. Adding, removing, replacing or scaling modules can target the product platform targeted towards specific markets or customer requirements. Core research challenges include efficient strategies and methods for determining the sub-division into modules and the number of variants of each, the recombination of these modules into product families of products, and how these are leveraged to target specific market segments and niches. Module is a set of components grouped because of certain relationships. The primary tradeoff in the platform design process is between commonality and distinctiveness [Simpson 2003], or between cost-cutting and increasing market shares [Ericsson and Erixon 1999].

2.1.2 Modularity Types

Modularization can be applied in the area of product design, design problems, production systems, or all three. It is preferable to use modular design in all three types at the same time; this can be done by using a modular design process to design modular products and to produce them using a modular production system or modular manufacturing processes.

(1) Modularity in products

Modularization is decomposition of a product into building block (modules) with specified interfaces, driven by company-specific strategies. The product of modularization (module) is defined as having two characteristics: 1) similarity between the physical and functional architecture of the design, and 2) minimization of the degree of interaction between physical components. In other word, module is a set of components grouped because of certain relationships, suggested through analysis of the product architecture tool and defined to comprise a module or subsystem. The difference between a module and a subassembly should be noted. A sub assembly is often the result of the assembly planning activity. Subassemblies are created because the product design does not permit entire assembly in one flow.

(2) Modularity in design problem

Most design problems can be broken down into a set of easy-to-manage simpler sub-problems. Sometimes complex problems are reduced into easier sub-problems, where a small change in the solutions of one sub-problem can lead to a change in other sub-problems' solutions. This means that the decomposition has resulted in functionally dependent sub-problems. Modularity focuses on decomposing the overall problem into functionally independent sub-problems, in which interaction or interdependence between sub-problems is minimized. Thus, a change in the solution of one problem may lead to a minor modification in other problems, or it may have no effect on other sub-problems.

(3) Modularity in production system

Modularity in production systems aims at building production systems from standardized modular machines. The fact that a wide diversity of production requirements exists has led to the introduction of a variety of production machinery and a lack of agreement on what the building blocks should be. This means that there are no standards for modular machinery. In order to build a modular production system, production machinery must be classified into functional groups from which a selection of a modular production system can be made to respond to different production requirements. Rogers [1997] classifies production machinery into four basic group of “primitive" production elements. These are process machine primitives, motion units, modular fixtures, and configurable control units. It is argued that if a selection is made from these four categories, it will be possible to build a diverse range of efficient, automated, and integrated production systems.

2.1.3 Modularization in automobile industry

(1) Studies on modularization in Volkswagen

In this chapter, modularization in automobile industry was described. This chapter presented explaining how modularization has evolved at Volkswagen. Volkswagen started to develop their modular strategy in the late 1990s starting with a platform strategy. The strategy was based on a common platform that could be used by several vehicle models within a vehicle class (Table. 2.1), also referred to as vehicle segment, where the platform belonged to a specific segment. To the platform, a hat was added and parts either belonged to the platform or the hat, which means that the parts always were designed for a specific car segment. The platform strategy allowed a platform to only be documented once and then copied for each vehicle model using the platform, but was limiting in the sense that a platform was specific for one segment of cars.

The platform strategy was further developed and in 2006, a module strategy was introduced, still based on a platform shared among vehicles in the same class but with the hat partially built up from modules. By contrast to the platform, the modules could be shared between segments meaning that cost savings could be made due to higher volumes while also facilitating variation.

Table 2.1: Classification of Volkswagen's vehicle segments

Segment:	A00	A0	A	B	C	D
Used for:	City cars	Supermini cars	Compact cars	Mid-sized cars	Executive cars	Full-size luxury cars

In 2013, the module kit strategy was introduced, based on one common modular toolkit for all vehicle segments and types of cars. The modules within the modular toolkit do not have the same limitation as the platforms, meaning that for a toolkit they can be shared both among different styles of cars as well as different vehicle classes. The evolution of modularization at Volkswagen can be seen in Figure 2.1.

The modular toolkit is organized according to Figure 2.2 below. The different brands are organized around the four module management areas, with the different subassembly kits subordinated one of the four areas. However, there are some slight differences from brand to brand under which module management area a subassembly kit is placed. A module database describes the content of the modular toolkit including for example which car projects are using which modules.

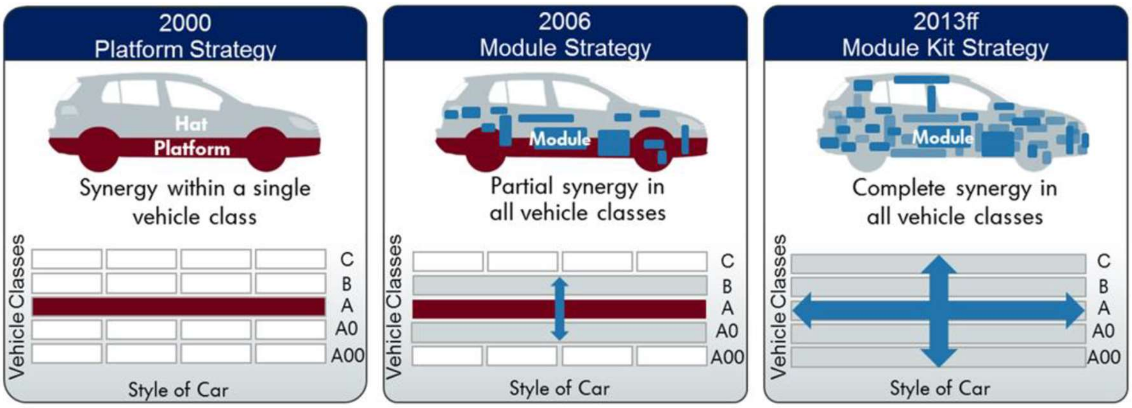


Fig. 2.1 The evolution of modularization at Volkswagen

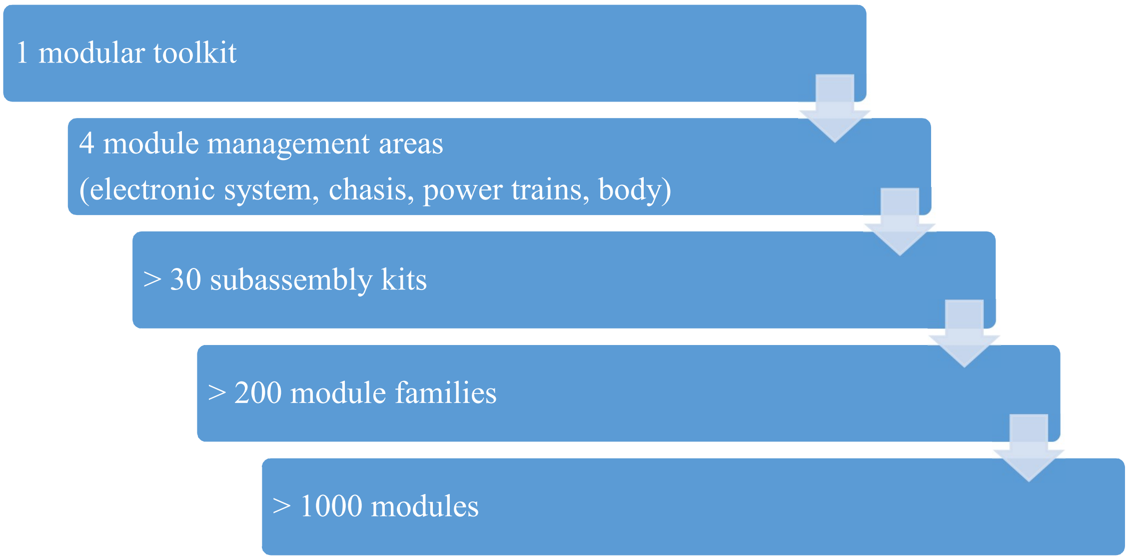


Fig. 2.2 The organization of the modular toolkit at Volkswagen

The module kit strategy is what Volkswagen uses today and the basic idea is to have product variety through standardized parts. The strategy is based on four vehicle toolkits which is associated with a certain number of modules from the modular toolkit, each toolkit described in a separate structure. The vehicle toolkits are based on the placement of the engine and the core architecture of the vehicle. The core architecture is flexible and permits of some variation dimensions, resulting in several instances with those specific architectural rules. Every instance can be considered as a separate platform, and in this way the vehicle toolkits can manage several vehicle segments.

The purpose with the module kit strategy is that every car using a vehicle toolkit can be constructed from the same basic modules, no matter which brand or model the vehicle belongs to. By sharing modules across brands and segments, cost savings can be made both by using already existing solutions in new applications and by shared development cost for new solutions. However, only combinations of modules are not enough to make the vehicle function. Additional parts such as screws etc. also need to be added in order for the car to be complete.

As mentioned, one of the main goals with the Volkswagens module kit strategy is to reduce the direct cost through larger volumes with less cost per unit. In addition, a higher quality grade is a desirable outcome, reached through standardized parts and production processes, as well as a shorter time-to-market and a well-optimized innovation cycle for each module.

The future regarding modularization at Volkswagen is to apply modularization in other areas than R&D and the product, and in 2012, a project to create a modular production system started. The project is called MPB, Modular Production Toolkit, and the first implementation is estimated in 2017-2018. The idea is to have modularization and modules on multiple levels in production; factory, section, manufacturing segment and equipment. By having predefined modules, the production can easily be adapted to handle several different vehicle types and higher production volumes and the goal is to use modularization to reach standardization in production.

At Volkswagen, the structure of a module is well defined. The module consists of a so-called a base module that is non-variable once a module is developed and shared across brands. The base module can contain hardware and software or only hardware. Apart from the base, the module consists of a variation content, which is the hardware and software creating the different variants of the module, and where every car project can chose the variation suitable for their needs and customers. The base module and the variation content constitute the module but a component is not complete with only that.

Apart from the module, an application content is also added. The application content is brand specific and it is the parts of the car that the customer can actually see or feel, hiding the actual module from the customer. The structure of a module is seen below in Figure 2.3.

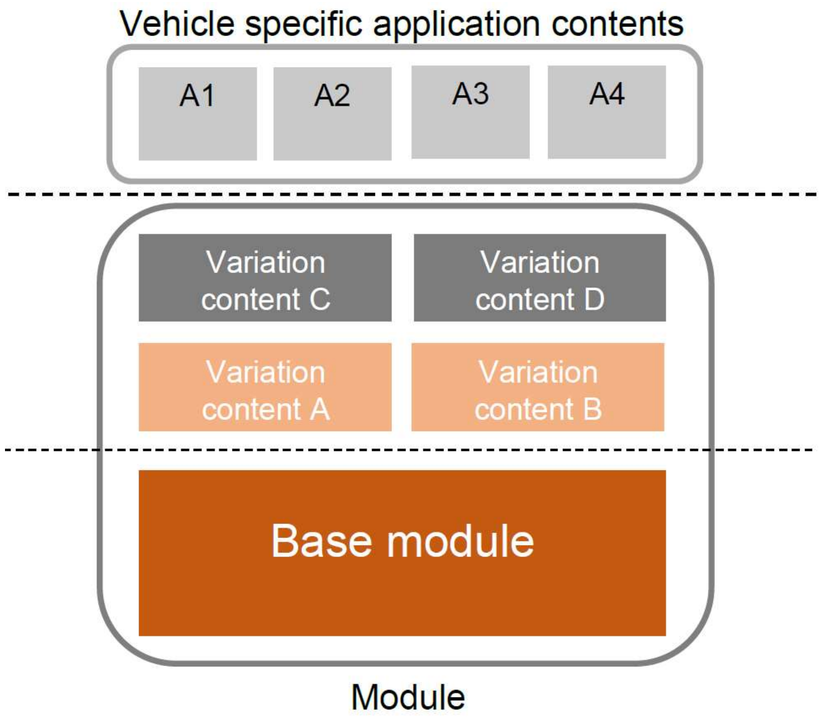


Fig. 2.3 The structure of a module at Volkswagen

An example of a Volkswagen module is the seat, which of course consists of a base module, a variant content and application content. The base module of a seat is the metal structure, or skeleton, which is the same for every variant of seat across all brands. What is variable depending on car project and customer segment is however if the seat manoeuvring should be electrical or mechanical, with or without airbag, heat or no heat etc. which constitutes the variation content of the seat module, creating different variants of the seat. Finally, the application content is added which for the seat constitutes material, colour, padding etc. which is the chance for each brand to differentiate themselves and appeal to their specific customer segment.

The idea of the module toolkit strategy is that every module belongs to one of the vehicle toolkits, and can then be reused by all vehicle types and vehicle segments belonging to that toolkit. These modules are therefore called “baukastenmodul” (toolkit module) and as an example, all cars built with the vehicle toolkit MQB can use the modules and module variants within that toolkit. Apart from that, it is possible for a module to be used by several vehicle toolkits but the module is still “owned” by one of them. This means that car projects using one vehicle toolkit, for example MQB, have to ask permission to use a module from another toolkit (MLB, MSB, MNB), but the processes supporting this is not yet well established in the organization [Madeleine and Emma, 2015].

(2) Studies on modularization in Renault-Nissan

The Common Module Family (CMF) is a modular architecture concept jointly developed by car manufacturers Nissan and Renault through their Renault–Nissan Alliance partnership. The concept covers a wide range of vehicle platforms. CMF is aimed cutting cost, production complexity, and improving the safety and environmental concerns of its vehicles, Nissan’s new CMF combines a number of the automaker’s own technologies with the modular vehicle concept.

It consists of five groups of interchangeable, compatible modules: engine bay, cockpit, front underbody, rear underbody and electrical/electronic. According to the companies involved in the development, CMF is not a conventional platform but rather a manufacturing system which can be applied to different vehicles. The actual platforms are built combining a limited set of common modules: a single module can be used for different platforms, covering different classes of vehicles, and so allowing a greater standardisation of components between both Nissan and Renault. Fig. 2.4 and 2.5 show the CMF concept in Renault-Nissan.

Nissan has long been promoting the sharing of platforms, or “commonization" as it likes to call it. One example is the FM platform, short for front-midship. It debuted in

2001 in the Infiniti G35 and has since gone on to spawn cars like the Infiniti FX crossover and even the Nissan GT-R supercar.

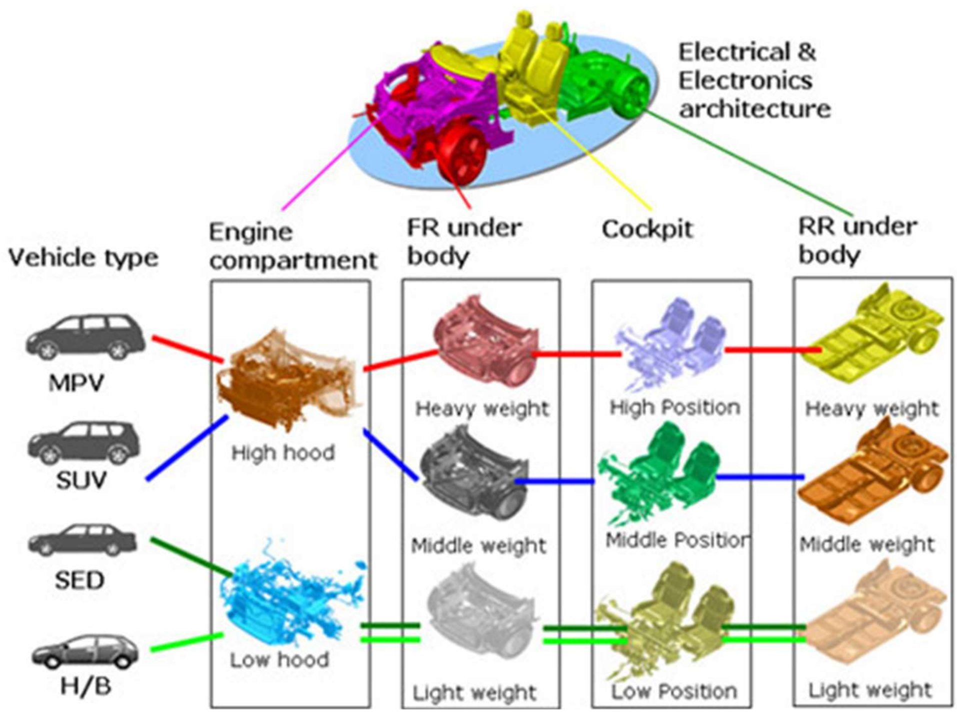


Fig. 2.4 The structure of a module at Nissan "CMF"

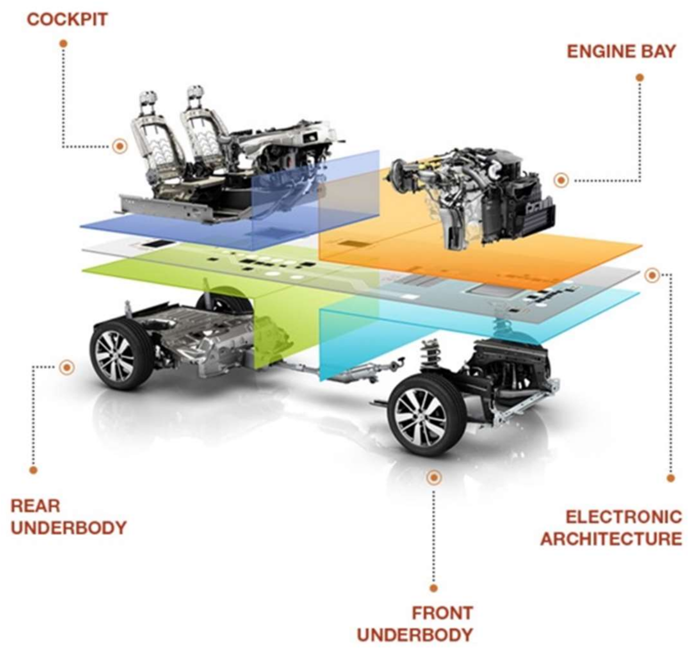


Fig. 2.5 Renault-Nissan's Common Module Family (CMF)

The CMF, on the other hand, will be used for more mainstream models and will underpin everything from compacts cars through to sedans and SUVs. The platform basically entails the use of four modules--engine compartment, cockpit, front underbody and rear underbody--as well as the architecture for electronic components, with each module having appropriate variations. Vehicles are designed by combining these modules in different ways. The CMF will initially be used in approximately 14 vehicle models worldwide with an estimated production of 1.6 million units annually. The first CMF vehicles were introduced through 2013 with Nissan's CMF-C/D models. CMF introduced of 51 new or updated models and 90 new technologies until 2016.

(3) Studies on modularization in Toyota

Toyota New Global Architecture – TNGA will be the foundation for all Toyota's future powertrain and vehicle development. It marks a revolution in the way Toyota designs, engineers and manufactures vehicles, streamlining the process by standardising the size and position of key components within standard new vehicle platforms.

Toyota takes the concept of platform sharing to a high level with TNGA by standardising components and their layout across different vehicle segments, and fully integrating both its manufacturing operations and its suppliers in the new concept at a very early stage. Toyota will substantially reduce the number and variety of different vehicle components, enabling smarter development and manufacturing that will increase efficiency and save time.

This will be effective whether the emphasis is on sporting character or practical packaging with plenty of rear seat legroom. The five layouts cover the requirements of the complete vehicle range, from compact sports cars to SUVs.

TNGA also brings a new approach to the design of the engine compartment, with a focus on placing components lower down in a more rationally organised "clean and tidy" space. This allows for a more attractive, lower hood, which in turn improves safety by giving the driver a clearer forward view. It also helps lower the car's centre of gravity, contributing to better handling and stability and a more engaging drive.

TNGA is not only helping Toyota create ever better cars, it also has a direct, positive impact on product development and manufacturing. In the most significant changes yet to the Toyota Production System, TNGA will ultimately lead to vehicle factories being smaller and more flexible, better able to respond quickly and easily to accommodate new or additional models.

Production lines mounted on the floor rather than being suspended from above will be simpler to install and adjust in length. Toyota anticipates TNGA will enable multiple models to be produced from the same line, supported by new, more efficient ways of producing parts and systems. Accommodating changes in design and specifications will also be simpler and quicker to achieve. Further gains will be made in environmental efficiency, by using equipment that is not only more compact, but also uses less energy.

The sharing of many common components among different vehicles in different segments will greatly reduce the number of different parts that have to be designed, manufactured and supplied.

Toyota calculates that TNGA will reduce the amount of manpower required for vehicle development by 20 percent, giving it more time to devote to designing ever-better cars. It reduces the level of investment required for bringing new products to market, while increasing the competitiveness and flexibility of Toyota's existing manufacturing plants.

TNGA is built upon two pillars — Core Strength and Emphasized Personality. Fig. 2.6 shows the two pillars of TNGA concept. Improvement of the basic performance of the core (essential parts) raises the level of all Toyota vehicles. By sharing high performance components, engineers are able to focus on accentuating the appeal of each model. TNGA plant produces 200,000 units annually, can build up to 8 different models on flexible lines and minimizes difficult tasks, making it easier to operate and maintain.

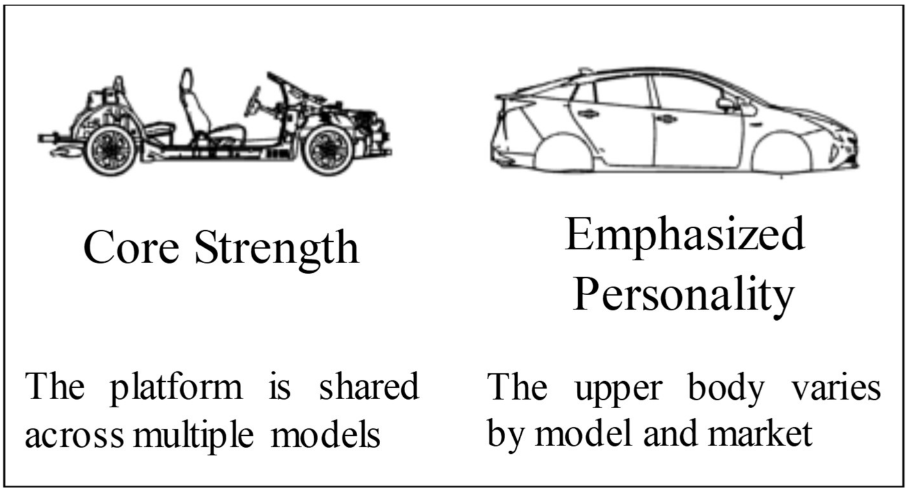


Fig. 2.6 Two pillars in TNGA concept

2.1.4 Modularization in other industry

(1) Studies on modularization in Atlas Copco Electronic

Atlas Copco Controls (ACC) develops and manufactures customized electronic products. Producing mainly servo drives, it has 300 different types, half of which are standard and half of which are customized. Of the 300 variants, about 60 represent 80% of the total yearly volume of 100,000 units.

Important changes in product design and company organization in the beginning of the 1990s put ACC on the road to modularization and component standardization. The standard assortment has been functionally and electronically modularized and can be customized by reprogramming the software.

The prevailing understanding among companies in the customized electronics business is that the lowest production costs are achieved through maximal integration of components on one single board. This has been seen as a strong opponent to modularization. However, the customer variation aspect and fitting of the product design to production processes more strongly favour modularization. In developing a new product generation, ACC decided to go for a modular design using the module functional deployment method since it forces the design team to consider the entire life cycle of the product.

The drive contains parts for logical control, input and output function, and a power supply. The power for the electronic inside is assembled close to the sensitive logical components. The combination of different components can give an infinite number or variants. Some special components have long delivery times and are costly.

Six of the highest weighted technical solutions were selected together with the power factor controller (PFC), since the PFC as an optional function requested only by a few customers. Thus, seven module candidates were selected:

- Power stage,
- CPU (central processing unit),
- Rectifier equipment (with capacitor),
- Logic voltage (input/output),
- Gate driver,
- Current sensor,
- PFC (power factor controller)

With these candidates as starting point, different module concepts were generated and evaluated. The four main modules of the finally chosen concept are represented in Figure 2.7. The terms 1/2 rectifier originates from the split of this components into a high-voltage part and a logic part due to conflicting module drivers within the rectifier. The modules are outlined as follows:

1. The CPU module, which includes logic parts and communication. The module drivers were carryover, process/organization, separate testing, and service/maintenance.
2. A power stage module, which includes the gate driver, and short circuit and temperature sensors. The module driver were carryover, common unit, process/organization, separate testing, and service/maintenance.

3. The main board module, which includes PFC, current sensor, logic voltage, 1/2 rectifier, and communication. The module drivers were different specification and process/organization.
4. The 1/2 rectifier module (high voltage), whose module drivers were carryover, common unit, process/organization, separate testing, and service/maintenance.

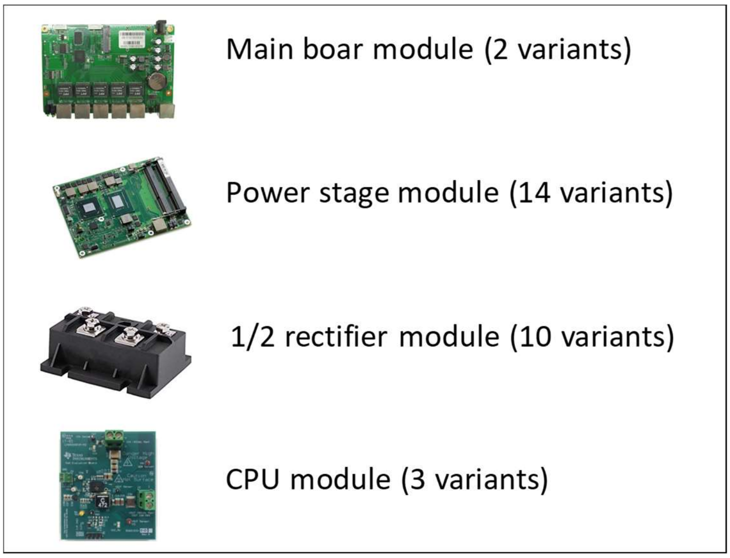


Fig. 2.7 Atlas Copco Controls modularized servo drives

2.1.5 Modularization in ship piping design

In ship design, the application of configuration-based design has been relatively limited, particularly in segments other than low-complexity, standardized vessels. Possible causes may be the complexity related to highly customized requirements and the extensive inter-relationships between different systems. Further, non-technical factors may be important, such as the shipbuilding culture for “handicraft”, and less tradition for long-term thinking. This leads to a focus on the individual projects rather than process improvements. In addition, compared too many other industries facing a similar complexity level, the typical length of a series in particularly European shipbuilding is short. This implies fewer projects to share the costs of developing a configurable product platform.

Modularization was adopted in the ship design. In a traditional design, these two functions are, at a high level, allocated to a single ship “module”. To the extent that this overall module can be separated into a hull module and a machinery & propulsion module, the interaction between these modules are complex and not well defined. For instance, an increase in speed would typically require a larger and heavier propulsion system that in the next step would require an increase in hull displacement. Thus, these two modules have a high degree of dependency, which is a typical characteristic for integral architectures. In general, integral architectures are characterized by the following properties [Ulrich 2008]:

- Product functions are implemented using more than one module
- A single module implements many product functions
- There is a high degree of (complex) interaction between the product modules

The opposite of an integral architecture is a modular architecture. Here, the different functions of the product are, to the extent possible, allocated to separate product modules, and the interaction between these modules is small or nonexistent. For the seaborne transport example, a more modular architecture could be achieved by separating the system into a cargo unit, such as a barge, and a propulsion unit, such as a tug. In this case, an increase in speed would only require a change in the “tug module”, and not per se influence the “barge module”.

As previously discussed, modularization and part arrangement with regard to piping design are important considerations to realize overall optimization of engine-room design in series ships. As such, many studies related to these aspects have been performed in the past. The concept of modularization was adopted in engine room design. In 1991 with the series of 1500 TEU container ships, modularization in engine room was applied [Baade et al.]. The result of all modules as follows:

- Low temperature cooling water module,
- High temperature cooling water module,

- Sea water cooling module,
- Separator module,
- Lubricating oil module,
- Fuel oil module,
- Starting air module.

In different example, Baade et.al. [1998] adopt the modularization concept in the engine room equipment. The system engineering group defined the equipment that have best opportunities to be modularized and locations with respect to other interfacing systems.

The modular standard containers or individual unit modules, with dimensions of 3m x 3m x 6m are connected together in the engine room factory, pre-assembled, pre-outfitted and tested. The space modules are pre-outfitted outside the ship hull in parallel with the construction of the hull and introduced into the steel hull from the top of the engine room hold. As a result, the 1700 TEU containership engine room consists of the following individual unit modules:

- High temperature fresh water system module,
- Low temperature fresh water system module,
- Sea water system module,
- Generator set module,
- Sewage system module,
- Evaporator module,
- Fuel oil system module,
- Refrigeration and air conditioning system module,
- Starting, working and control air system module,
- Integrated firefighting system module,
- Lube oil system module.

Figure 2.8 is the illustration of the single module with foundations. In this research, module is a big unit of one system in the engine room. Therefore, the total modules in the engine room for one ship is about ten modules.

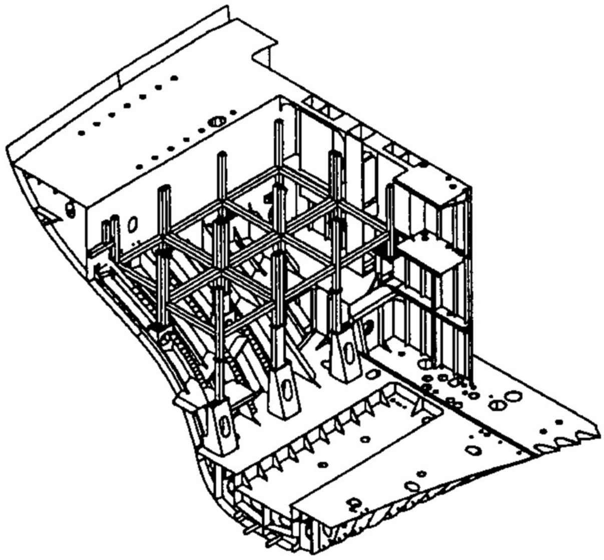


Fig. 2.8 Details of single modules with foundations

The other example of modular outfitting is proposed by Rubesa et al. [2011]. The modular outfitting approach in this study is based upon pre outfitting in the workshop. It begins in the early stage of design, especially in machinery arrangement design. At this stage, functionally related equipment, systems, and tanks are located to reduce the distributed system footage and maximize unitisation and standardisation potential. The goal is to identify the largest possible assembly of the equipment and outfitting components that can be completed in the workshop, assembled concurrently with hull construction and easily lifted without exceeding crane-lifting capacities and workload during the installation. The final module content and layout is confirmed by a series of studies, build strategy, and preliminary system routing. Thus, modules are optimised, based upon engineering, spatial, regulatory, and economic parameters. The result of modularization in this study is shown in the Fig. 2.9. They divide the piping system in engine room in to 6 big modules. The effectiveness of this concept is evaluated using the cost benefit estimation.

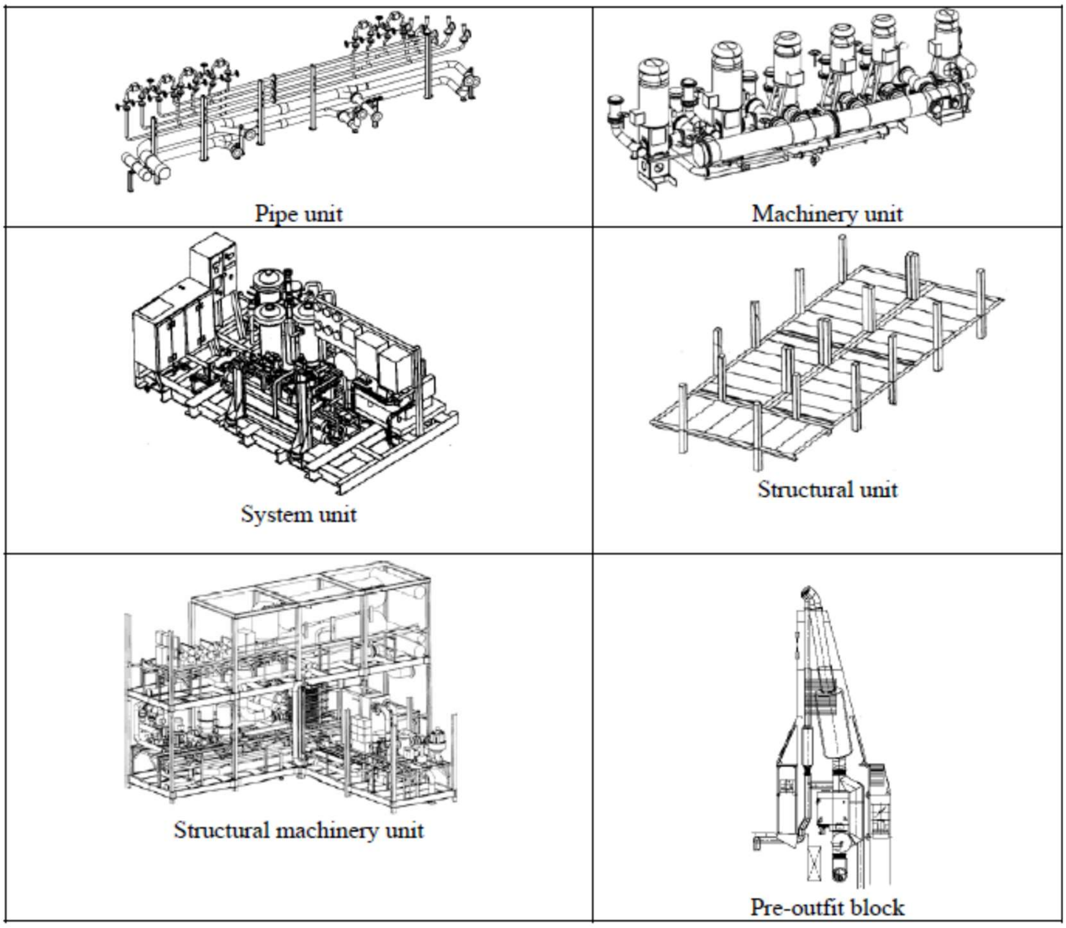


Fig. 2.9 Details of single modules with foundations

In this this study a new procedure for shipbuilding cost benefit measurement is developed, as a consequence of using the modular outfitting concept within the shipbuilding process. The result will be applicable in observed shipyards and wider, through the procedure for fast and simple selection of the existing level of advanced outfitting, with the possibility of using a multi criterial decision process in defining a strategy for further improvement of the ship outfitting process with an exact indicator for impact in cost reduction.

The other concept of engine-room modularization introduced by several researchers, Cort and Hills [1987], Hills and Wels [1989]. These studies, however, resort to a rather simple modularization approach that involves use of a standard compartment for each ship. Standardization of modules for various series ships has not been considered previously.

Jaquith et al. [1996] proposed a concurrent engineering system to simplify the construction of outfitting and equipment used in the engine room. Big data system was adopted to identify all components in the engine room. Further, all components were grouped inside the big outfit unit (module). Fig. 2.10 shows the module result of this study, consists of 11 big modules in engine room. A novel modularization methodology was reported by Tomassoni et al. [2003]. In their study, they proposed an advanced design methodology of grouping machinery equipment into a functional volume and block and an interface was considered between them. As the result, the design cost, production cost and construction cycle time were significantly reduced. All researchers involved in the study, used their experience to design the modular outfitting and components inside the engine room. Consequently, an engineer-experience-based modular arrangement was created.

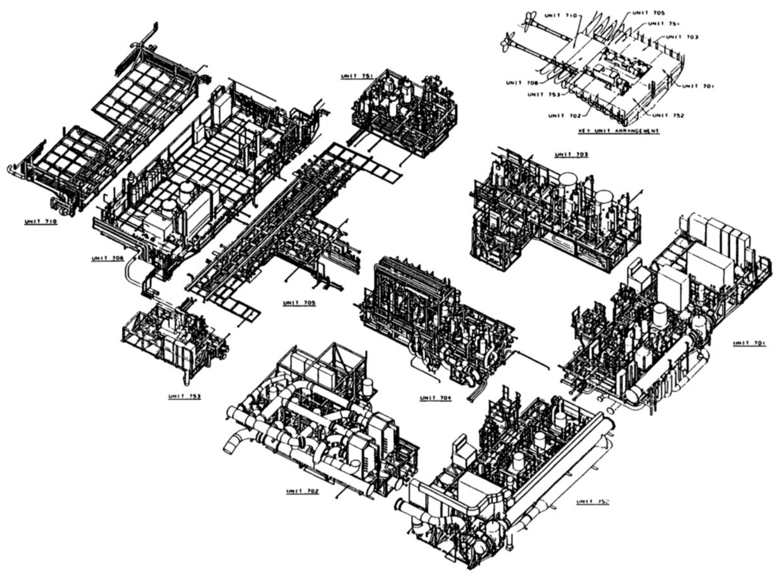


Fig. 2.10 Modular design in engine room

2.1.6 Modularization using design structure matrix (DSM)

(1) Definition of DSM

The DSM is a network modelling tool used to represent the elements comprising a system and their interactions. DSM is particularly well suited to application in the development of complex, engineered systems and has to date primarily been used in the area of engineering management. The DSM is represented as a square matrix, mapping the interactions among the set of elements. A highly flexible tool, DSM has been used to model many types of systems.

A DSM can represent a system architecture in terms of the relationships between its constituent components. Such a model informs system decomposition into subsystems. Intelligent decomposition or partitioning is important to managing system complexity. The architectural decomposition scheme has ramifications for the ease of system design and integration. The importance of informed architectural decomposition has led to several matrix-based models.

In order to modelling and analysis of a system, a four-step approach is required.

- Problem statement
- Data collection
- Modelling
- Result

The examples of modularization using DSM are explained in the followings:

(2) DSM in automobile industry

- **Modularization in automobile climate control system**

The modularization study in the climate control system is described by the following points:

1. Problem statement

The climate control division of Ford Motor Company (Ford) wanted to better understand the network of component interactions in the climate control systems it designed and produced for Ford cars and trucks. These systems are comprised of many interacting components. The objective of this study is to looking for new insights regarding how the components functioned together as modules and how system engineering and integration activities could be improved.

2. Data collection

Trough discussions with several system engineers at this division, then captured the system decomposition as a list of 16 typical components. The types of interaction in this study is divided into 4 types; spatial adjacency, energy transfer, material transfer, and information signals, and quantified these on a 5-point scale (from -2 for detrimental to +2 for required).

3. Model

The composite DSM shown in figure 2.11 contains the ratings of all four-interaction types across all of the components. Clustering analysis using any one dimension of interactions is relatively straightforward, as illustrated by the clustered materials DSM shown in Figure 2.12. Clustering using any weighted function of all dimensions of the interactions is also possible. The clustered composite DSM shows such a result in Figure 2.13, revealing the three clusters identified in the materials DSM plus a group of interacting elements.

4. Result

After modularization, three important clusters (modules) such: interior air, refrigerant, and front-end air were identified by considering only the material transfer-type of interactions, as shown in the clustered materials DSM (Figure 2.11). The clustering analysis with the other three dimensions also performed. Finally to create the composite clustered DSM, combination of the results of each of the four single-dimensional clustering analysis is needed.

Considering the composite clustering results, several observation can be made. The three clusters included interactions of the material, energy, and spatial adjacency types. However, in the highly integrative controls/connections chunk, the interactions were of the spatial and information types. This suggests that for some systems, certain types of interactions may be clustered as product modules, whereas other interactions are more integrative across the entire product or system. The four interactions types used in this analysis seemed appropriate for this application. In general, the other interaction types might be better suited to representing other types of systems.

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

NOTE: BLANK MATRIX ELEMENTS INDICATE NO INTERACTION (FOUR ZERO SCORES).

Legend:

Spatial: S E :Energy
Information: I M :Materials

Fig. 2.11 Composite DSM including interactions among components of four types

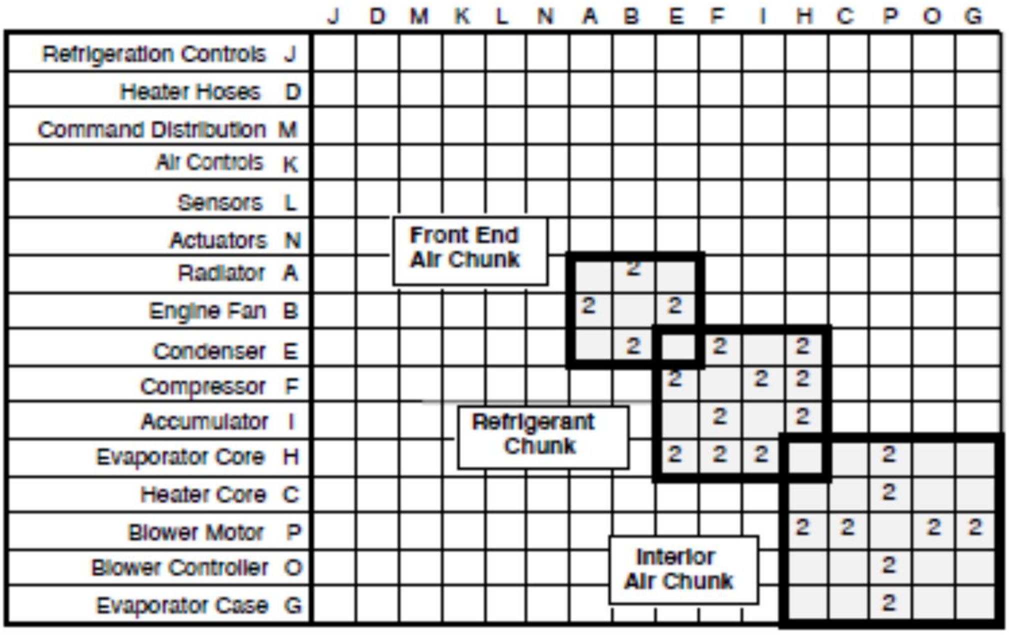


Fig. 2.12 Clustered material DSM

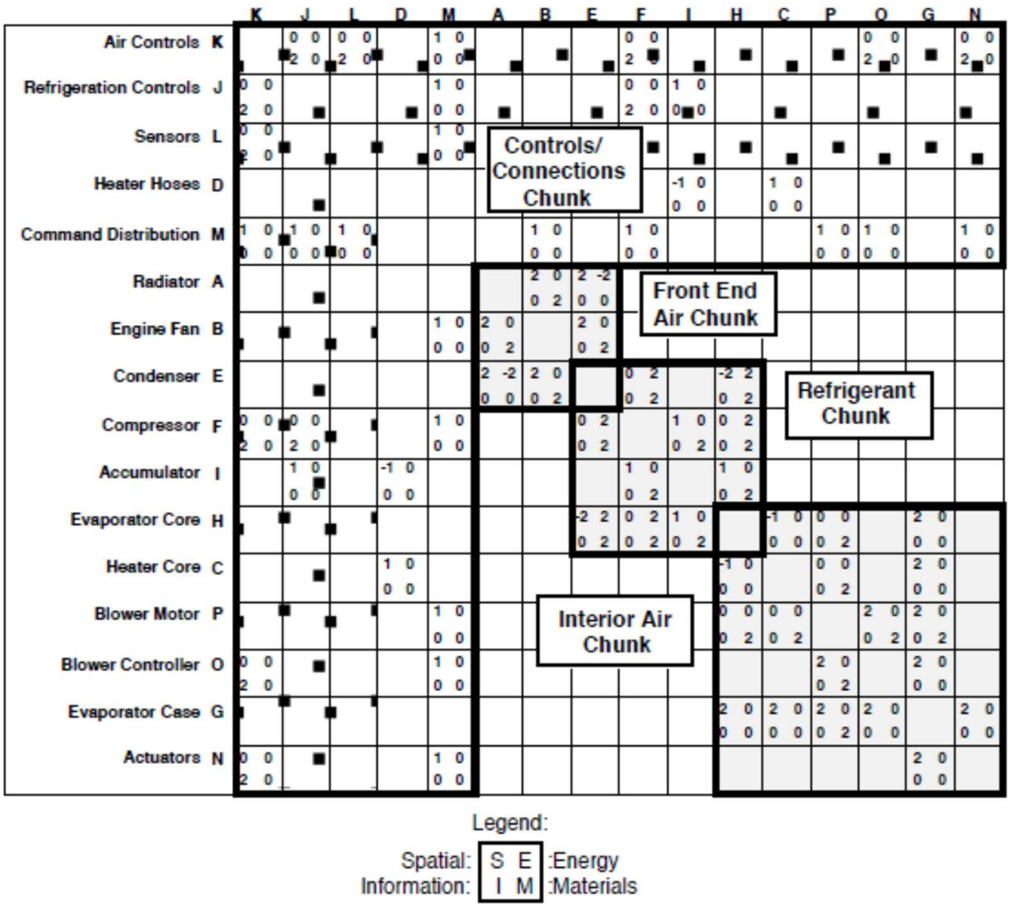


Fig. 2.13 Clustered composite DSM

(3) DSM in other industry

- **Modularization in commercial aircraft jet engine**

The modularization study in the aircraft jet engine is described by the following points:

1. Problem statement

Pratt & Whitney, a division of United Technologies Corporation, produces and supports aircraft jet engine, industrial gas turbines, and space propulsion systems. Development of a commercial aviation jet engine is a highly complex process involving hu8ndreds of engineers working simultaneously on the various components and subsystems. This DSM application investigated the system engineering and system integration aspects of the jet engine development process through a product architecture DSM. The engine, as illustrated in Figure 2.14, is decomposed into eight subsystems, which are comprised of 54 major components.

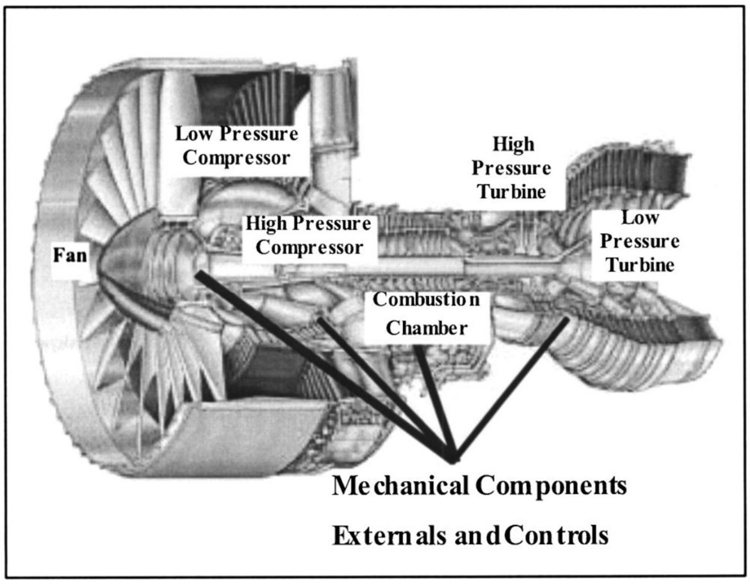


Fig. 2.14 Commercial aircraft jet engine

2. Data collection

In this study, five interactions types are proposed based on the result of interviewed with some engineers. These interactions such as: spatial adjacency, energy flows, material flows, structural connectivity, and information flows.

3. Model

The binary DSM model displayed in Figure 2.15 shows the decomposition of the jet engine in to eight subsystems and 54 components. Interfaces are indicated in the DSM using X symbol cells between pairs of components.

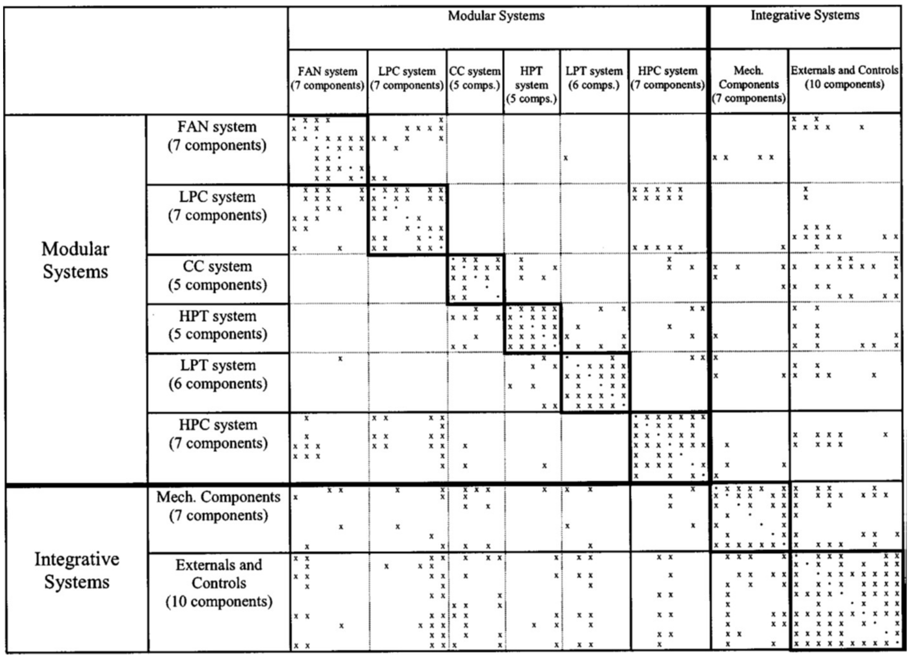


Fig. 2.15 Design interface matrix

4. Results

The DSM model identified six of the subsystems as modular, in that each subsystem primarily had interfaces among components within the subsystem. These modular subsystems are the fan, low-pressure compressor, high-pressure compressor, combustion chamber, high-pressure turbine, and low-pressure turbine.

The DSM also showed that the remaining two, more spatially distributed, subsystems were more functionally integrative across the engine. These distributed subsystems are the mechanical components and the external controls. They tended to have more interfaces among components of different subsystems and relatively few interfaces within each subsystem.

Identifying the pattern of component interfaces both within and across subsystems helped the engineering manager to better manage the highly complex challenge of system engineering. Their system engineering practice had been largely focused on the interactions inside the modular subsystems. Based on this analysis, they were able to focus more attention on the component interfaces across the subsystems.

- **Modularization in NASA Mars pathfinder technology readiness**

The following points describe the modularization study in the NASA mars pathfinder:

1. Problem statement

The US National Aeronautics and Space Administration (NASA) has a broad mission to conduct human and robotic space exploration, scientific discovery, and aeronautics research. In the mid- to late 1990s, NASA launched several robotic spacecraft missions to demonstrate new technology while also executing these missions with shorter development times. Successes in this approach included the landing of the Mars Pathfinder in 1997, which provided views of the Martian surface and demonstrated the use of a small, robotic rover. The successes were offset with some failures, most notably the loss of both the Mars Climate Orbiter and Mars Polar Lander in 1999.These failures motivated investigation of the effectiveness of DSM to provide a comprehensive system view of the product architecture and the effect of technology maturity and risk in system components.

2. Data collection

Data provided by NASA employee and some researchers from MIT System Design section. Cases were also selected based on availability of data related to the spacecraft architecture and subsystem technology maturity. One of these cases was the Mars Pathfinder spacecraft, which landed successfully on the surface of Mars in July 1997 and deployed a robotic rover.

3. Model

A technology risk DSM (TR-DSM) is based on a product architecture DSM using a decomposition of the major components of the spacecraft. The TR-DSM is generated using a three-step process. In the first step, a product architecture DSM is generated using values for the strength of each component interface dependence.

The interface dependency value assigned to the DSM cell is obtained by summing values representing the physical, energy, and information interactions that exist between a pair of elements. In this DSM example, a physical interface value of 2 is assigned where a direct physical interface exists. An energy interface value of 2 is assigned where there is direct energy transfer such power, propulsion, or thermal loads. The information interface was assigned a value of 2 where there is direct transfer of information between components and a value of 1 where information is transferred indirectly between components.

In the second step of the TR-DSM generation, component is assigned a technology risk factor (TRF). The TRF scale ranges from a value of 1 for the most mature components to a value of 5 for the highest risk or unproven components. The specific value assigned is based on criteria set by NASA's technology readiness level (TRL) definitions. In the TR-DSM (Figure 2.16), a column and row are added next to the component names, and the TRF values are placed in the DSM cell adjacent to the component name. The final step of the TR-DSM generation is calculating the value to be placed in each cell of the DSM using the certain formula.

4. Results

The TR-DSM can be used to highlight areas of development and operational risk. One of the major objectives of the Pathfinder mission was to demonstrate new technologies that could help reduce the cost of delivering scientific instruments to Mars. These components included a radiation-hardened computer based on commercial hardware, utilization of distributed processors linked together with a data bus, telecommunications circuit boards, and components that supported the strategy for aero-braking entry, parachute descent, and touchdown with airbags surrounding the lander.

The resulting TR-DSM shown in Figure 2.16 identifies several clusters of technology risk areas. For example, the entry, descent, and landing (EDL) subsystem shows up as an area of high technology risk. The high values result from set of interfaces identified with relatively high dependence between components with high technology risk factors. The interfaces associated with the telecommunications, the landing instrumentation, and the rover showed clusters of high technology risk.

The Mars Pathfinder project had an exceptional risk management approach, and the case study can be used to assess the effectiveness of the TR-DSM in identifying the same project risks. The TR-DSM can be analytical tool throughout a project's development life cycle for identifying and communicating high-risk areas in a single-system view. High TRF values can be used to identify subsystems and components requiring a thorough mitigation strategy during development.

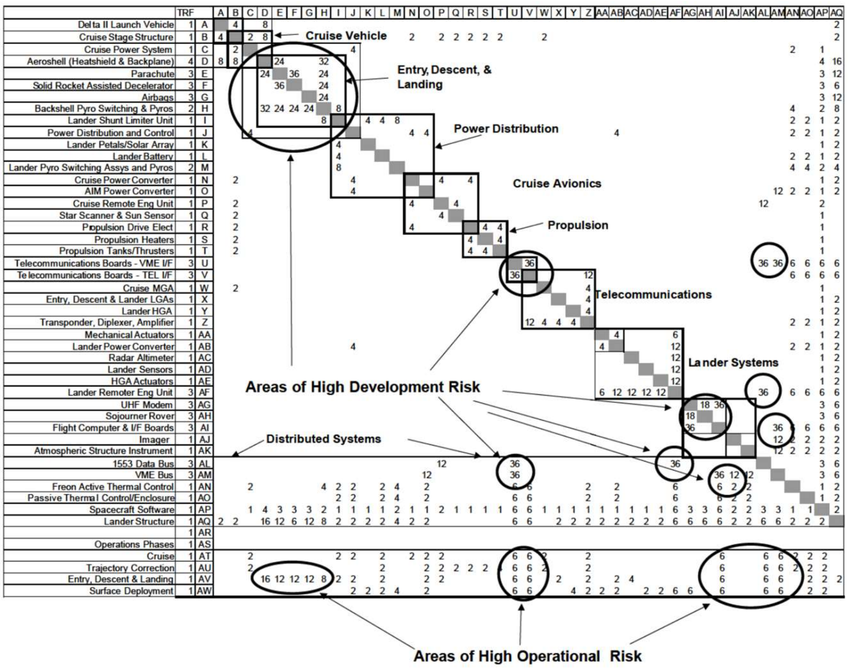


Fig. 2.16 Technology Risk DSM for Mars Pathfinder

(4) DSM in ship piping design

In 2009, automatic modularization of the engine room was introduced by Koga et al. [2009]. They adopted the design structure matrix (DSM) to generate a modular division of the engine room of a ship, through use of the modular division algorithm, and subsequently evaluated the result using functional completeness and module independency.

Modularization divides the development of the engine room into the development of individual modules through the determination and standardization of inputs and outputs. For the modularization of design, it is very important to solve the modular division problem. The reasons for this can be categorized into the following three issues:

1. Modular division decides modular functions, while modular functions determine the technical content to be developed, tested, and guaranteed as a module. Modular functions also affect the collaboration between suppliers.
2. Modular division decides the accuracy of a judgment made by the other components, predicts a failure, and determines the size of the control system.
3. Modular division decides the ability to maintain and operate the modules.

The modular division problem is very important, and it is remarkable that a systematic method for the modular division of a complex plant system has not yet been established. Hence, this paper proposes such a design method. On the basis of the proposed modular division algorithm, a design environment for trial-error of the modular division is implemented. Their study proposes a computer algorithm and a division system to address the modular division problem of an engine room. The algorithm enables the designer to achieve high functional independence between modules and to reduce the complexity of the entire engine room. In order to describe the modularization method, this paper addresses the following three methodologies for a formalization of the modular division problem:

1. A network representation model of the system diagram.
2. A description method for the propulsion system as a superimposed network of system diagrams.
3. A division and evaluation method of the superimposed network as a modularization of the engine room.

To evaluate the effective modular structure, functional-completeness and system-independence analyses of the module were performed. Fig. 2.17 shows the model of module defined on the basis of the division line.

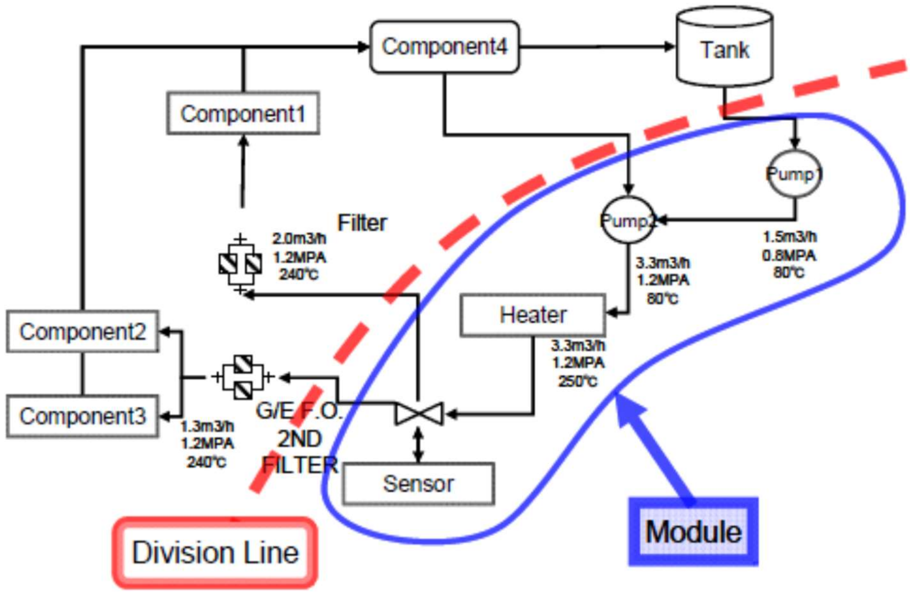


Fig. 2.17 Model of a module defined on the basis of the division line

It is difficult for a designer to grasp all the inputs and outputs of an integrated plant model due to its complexity. In order to understand, visualize, and calculate the relationships between modules, a matrix description of the modular structure is proposed in this paper. An example of the matrix representation of the integrated plant network in Figure 2.18 is shown in Figure 2.18. A modular matrix is defined as a square matrix, whose rows and columns are defined as the list of the entities (components), and whose cells are defined as the input and output flows between entities. The modular matrix represents the function, input, and output of the module.

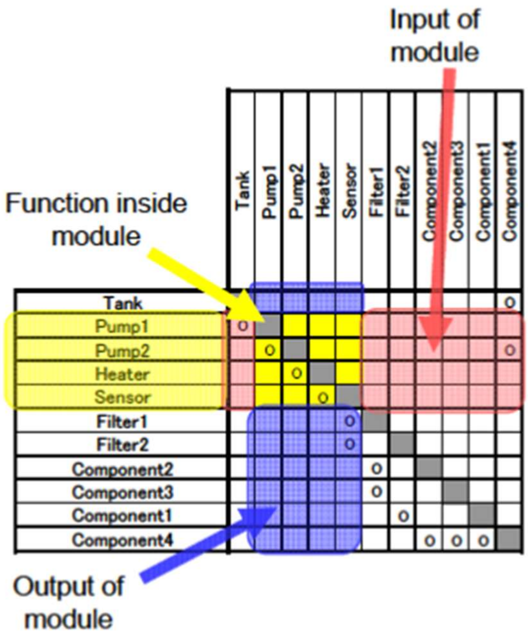


Fig. 2.18 The modular matrix: modular function, input, and output

In this study, the number of the entities (components) is 155, and the number of the attributes is 986. The number of the function diagrams corresponding to each flow is eleven (fuel oil supply system, steam system, exhaust system, air intake system, and so on). The integrated plant model has the combined information of 11 function diagrams. Inorder to evaluate the result of DSM, the functional completeness of the modules (FCM) and the system independency of the modules (SIM) are used.

Two different modular division results are compared in Figure 2.19. Division plan 2 represents the better of the two plans, and has a high SIM. Division plan 1, on the other hand, is inferior because it has a low SIM, as is shown in Figure 2.19. The system complexity of division plan 1 is high because there are many flow relationships between individual modules. In contrast, division plan 2 reduces the complexity of the system because there are fewer flow relationships between modules. As a result, division plan 2 divides a complex system design into a simpler modular configuration.

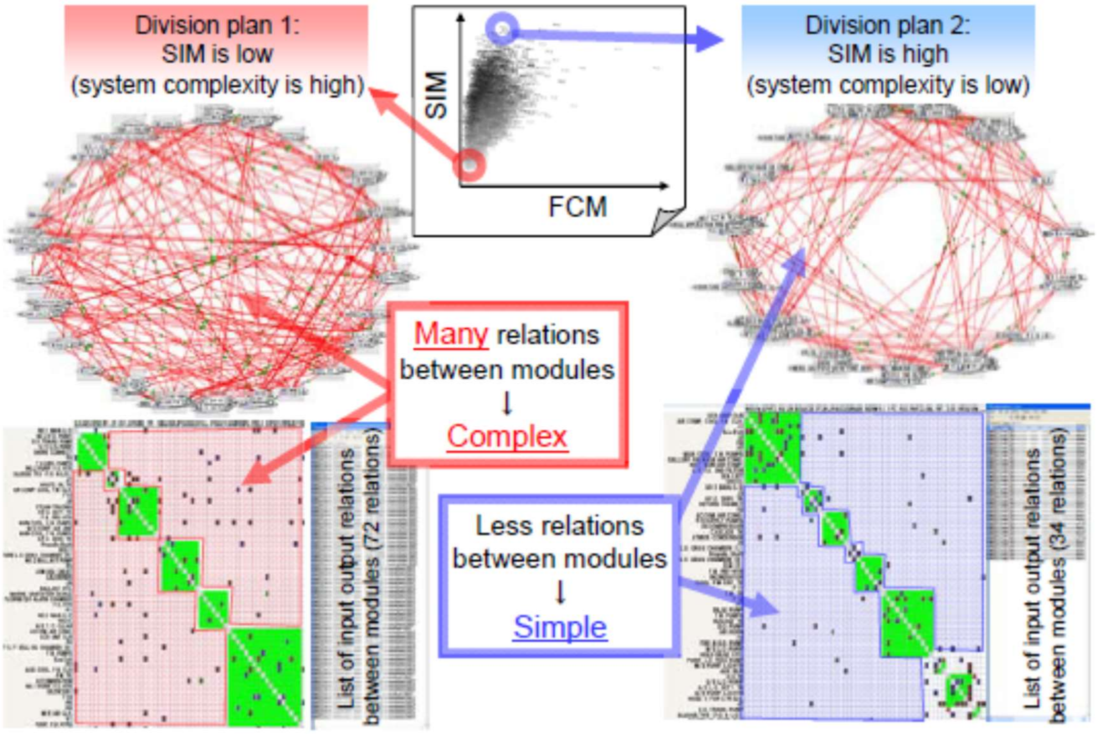


Fig. 2.19 The result of modularization

2.2 Studies on Automatic Arrangement

2.2.1 Definition of automatic arrangement

Automatic arrangement is the placement of several components in the target space by considering some constraints. In the automatic arrangement, the optimization algorithm is required. The computer assistance is required because of its ability to handle tedious computations and evaluations very rapidly, far more rapidly than is practical by human brain power with the aid of pencil and paper. It is this characteristic that makes the computer important to the more successful attempts to improve arrangement design techniques.

However, computer technology coupled with the mathematicians brain power is not yet to the point where it is practical to deterministically evolve an optimum arrangement.

Therefore, some optimization techniques like heuristic procedure are required. Using the heuristic technique i.e. genetic algorithm is powerful way to obtain the optimized arrangement in the complicated problem.

2.2.2 Automatic arrangement method

Developing machinery arrangement is an important step because of the impact of the layout on the operation, repair, and maintenance of the machinery. Because of the complex and precise nature of the machinery arrangement layout, many researchers have proposed various approaches to assist in the layout design such as exact procedures, heuristics, neural networks, fuzzy logic, and expert system. Automatic arrangement is required to solve the complicated problem of part arrangement inconsideration some constraints condition. Using some algorithm as denote above, the automatic arrangement method is easier to meet the optimized arrangement in the several applications.

2.2.3 Studies on the automatic arrangement using Genetic Algorithm

(1) Plant arrangement design in Petroleum Company

- Problem statement

In the industrial park, the plant arrangement design is the keyway to help enterprise improving production efficiency, operation safety and energy saving. In the petroleum factory, the arrangement of plants is very important due to the reducing of the piping cost and material flow. In order to optimized the plant arrangement, Wu et al. [2016] proposed the optimization method using Genetic Algorithm (GA). The objective function in their study is to minimize the total pipeline cost and the economic property damage which is caused by safety accidents simultaneously.

- Data

In this study, they conducted nine plants as the object research including four kinds of piping system. The case study has three scenarios based on the different optimization target in order to illustrate the proposed method. They are the cost of material piping, the total piping cost and the sum of piping cost and safety cost. There are nine plants in the factory. The steam is distributed at three levels: high pressure steam, medium pressure steam and low pressure steam.

- Optimization Algorithm

GA is used through MATLAB in this paper to obtain the optimal scheme of plant layout. It mimics the process of biological evolution. GA starts from an initial population and repeats the operations of selection, crossover and mutation until the optimal result is obtained. For the calculation of steam piping, Kruskal algorithm is used to obtain the shortest length. It is a kind of minimal spanning tree algorithm which calculates the connected graph with weight. And the steam usage is described by binary variables. In order to optimize the shortest path of steam piping, all the plants which need steam and unpredictably other plants need to be combined. The length and arrangement of piping can be obtained through the calculation and verification of Kruskal algorithm.

- Result of Optimization

The three levels of steam piping are the simplest, as shown in Figure 2.20. Because the pipelines are arranged without passing the redundant plants. Besides, the piping of material flows is concentrated together, illustrating the decreasing of the piping cost. The different areas indicate the different radius of personnel and property losses. The scope losses is greater in the area with more shallow color. The shallow ones contain areas with deep colour. Plant 7 is located in the bottom right corner. This is one of the important factors lead to reduced cost of safety.

The proposed method in this study enriches the piping cost on the basis of improved calculation. The enriched piping consists of material flow and steam flow results in the economic cost. Additionally, the safety issue is added in the objective function.

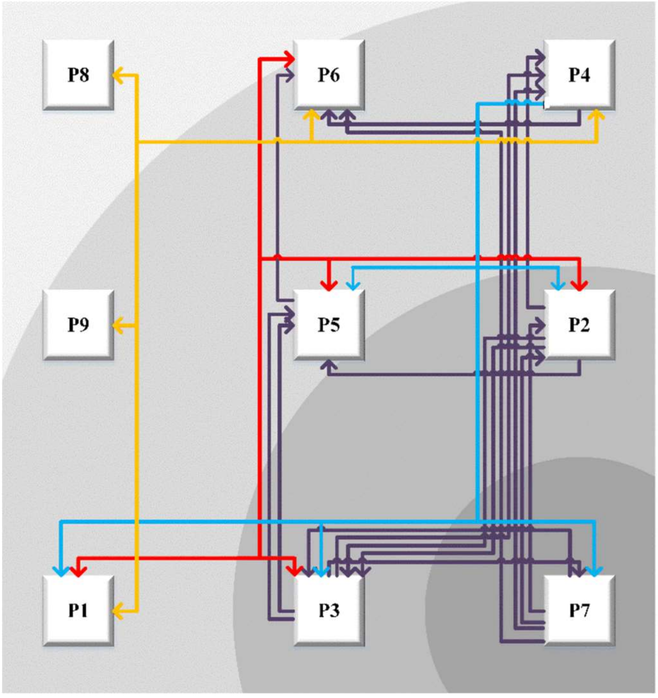


Fig. 2.20 Optimized arrangement of plants

(2) Instrument and piping arrangement design in engine room

- Problem statement

Automatic design of piping layout is challenging since it is composed of several numerical and/or combinational optimization problems, e.g., routing problems of pipes including branches, and arrangement problems of equipment. Kimura [2011] proposed the automatic design system for piping and instruments arrangement. This paper presents a new approach that the branches of pipes are considered to be a variety of equipment. Accordingly, the pipe routing problems are fairly simplified by removing the branches, and it derives a lot of efficient algorithms to solve the pipe arrangement problems.

- Data

To confirm the effectiveness of the proposed method, it was applied to two types of pipe arrangement design problems: One has five valves, one pump, and five branches, and the other has seven valves, one pump, and six branches. The PID consists of seven valves, six T-branches, and four external connections.

- Optimization Algorithm

To provide a good initial population for the MOGA, a new heuristics making use of self-organization techniques to arrange equipment is proposed. The efficiency of the approach is demonstrated through two experiments, one is a designing problem including five valves, one pump, and five branches, and the other includes seven valves, one pump, and six branches. It is three-objective optimization (minimization): The first is material cost, the second is the number of the elbows, and the third is the valve operability cost. The material cost is estimated by multiplying the length and the diameter of the pipes

- Result of Optimization

On the first stage of the optimization, the proposed system attempt to generate the initial population partly using Random Arrangement method. In the case that the equipment and pipelines are to be arranged into narrow design space, the Random Arrangement method can hardly find feasible solutions, therefore the calculation time to generate the initial population takes too much. Figure 2.21 shows a solution in the problem of seven valves. The yellow transparent box is a pathway, the red box is a pump, and the dark grey objects are obstacles.

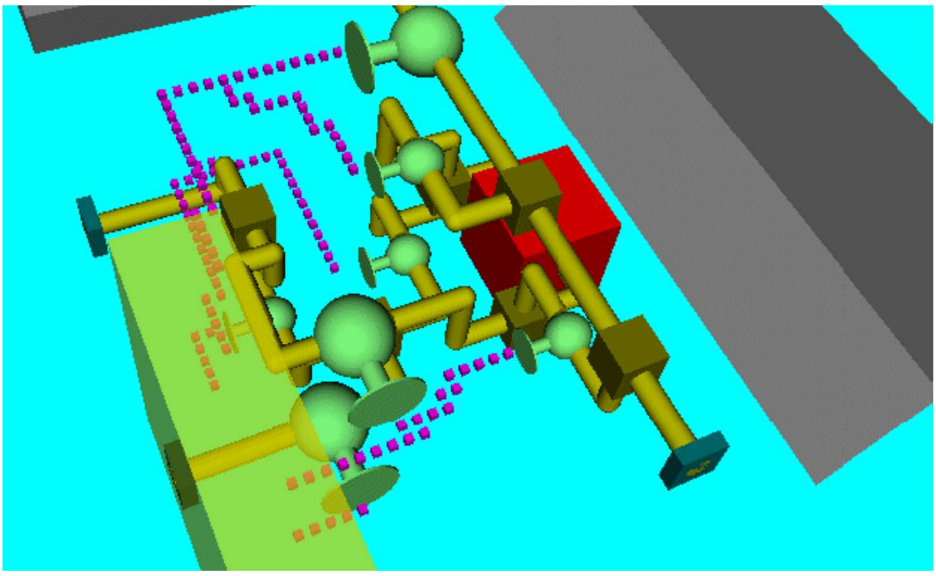


Fig. 2.21 Machinery and pipe arrangement

2.2.4 Studies on the automatic arrangement using Particle swarm optimization

(1) Equipment arrangement design in Ethylene Oxide Plant

- Problem statement

After selecting the type of a process and determining the specifications of all equipment, the next step is to design a plant layout how to determine the location of each process units in an area with significant engineering creativities, heuristics, prior knowledge, and so on. Thus, the total construction cost is the combination of the purchasing equipment cost, the piping cost and the site cost. Moreover, a plant layout should secure enough maintenance and safety spaces for efficient accessibilities and safety requirements to repair process units and prevent domino impacts. In addition, in case of off-shore plants, multi-floor processes have to be installed in the limited site. These issues make the plant layout problems very difficult and complex. In order to solve above problem, Lee [2015] proposed the optimization method using the particle swarm optimization (PSO).

- Data

To confirm the effectiveness of the proposed method, the 7 equipment such: reactor, heat exchanger, absorber, flash drum, pump, etc. are carried out to be arranged in the multiple floor. By using the proposed algorithm, the optimal layout is obtained due to the reduce of the pipeline cost.

- Optimization Algorithm

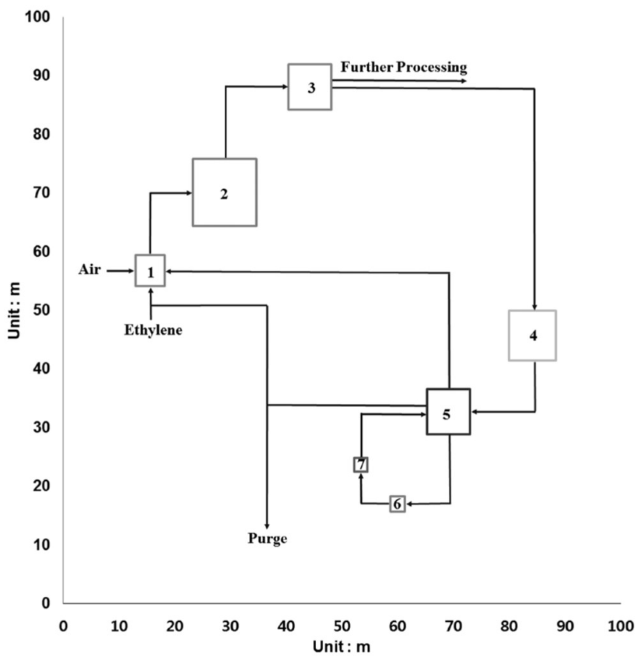
The locations of each equipment items should be determined to minimize the total costs. As explained in the previous section, there are many constraints for the working spaces and passages, which have many limitations for the mathematical formulations. In addition, the type of constrains vary according to the floor and the type of a process. Thus, it is not always possible to use conventional tools such as GAMS for solving this problem, since the derivatives of the constraints are not available. As an alternative, PSO (Particle

Swarm Optimization) technique is employed in this study. PSO is a population based sampling optimization technique motivated by the social behaviour of collection of animals. It starts with randomly generated swarms, called particles, remember the best solution found. The particles move around the solution space with adjusted velocities and have a tendency to fly towards the global optimal solution over the optimal procedure.

The characteristic of this research is conducted multiple floor to arrange the equipment and pipeline. The objective function is a summation of pipeline and pumping costs. In addition, various safety and maintenance issues are transformed into inequality or equality constraints.

- Result of Optimization

In the case of only one floor is available and the floor size is not fixed. Therefore, the goal of this case is to find the best plant layout with the smallest area, since, the cost of land accounts for the largest portion for building a plant in general. Figure 2.22 shows the best results of the arrangement during PSO iterations.



Number	Equipment
1	Reactor
2	Heat exchanger
3	EO absorber
4	Heat exchanger
5	CO_2 absorber
6	Flash drum
7	Pump

Fig. 2.22 Optimal solution incase only one floor is available

2.2.5 Studies on the automatic arrangement using Fuzzy function

(1) Equipment arrangement design in engine room

- Problem statement

Basically, machinery arrangement should be designed to maximize the functions of the machines and system that are arranged in the engine room area. In the design process, many criteria must be considered such as how to effectively use people, machines, space, and energy, how to minimize capital investment, and how to ensure the ease or repair and maintenance of the machinery.

The relationship of activities between machines and the function of the machinery itself are important elements in the design of the machinery arrangement. Certain machines, however, need to be arranged close to each other to maximize machinery function, because the exchange between machines can effect their individual performance. For a large composite system such as a ship, there are many units that have a specific relationship to other units and to the arrangement of the unit in the space.

Kim et al. [2009] proposed the machinery arrangement design based on the fuzzy function. In this study, they conducted 15 components to be arranged in the engine room. In order to evaluate the effectiveness of the result, they used evaluation function. The evaluation function comprise of 4 aspects, such: convenience, pipe length including number of pipe bends, distance between components and required minimum area. If a machinery library is constructed, any expansions are possible and structural and functional characteristics of each machine can then be constructed using the database. In this study, all machines are illustrated by block meshes. The machine size is horizontal and vertical length of block connects the vertices of the machine with a perpendicular straight line. By constructing a block machine, they can use coordinates to describe the location of the machines. This is a convenient way to create a program that will calculate the distance between machines, and between each machine and cell.

- Data

To confirm the effectiveness of the proposed method, the 15 equipment such: power supply, cooler, air inflow controller, etc. are carried out to be arranged in the engine room area. By using the proposed algorithm, the optimal layout is obtained due to some objectives function.

- Optimization Algorithm

Fuzzy function is adopted to optimized the arrangement of this study. In the evaluation of the arrangement design of a ship, all elements that are involved in the evaluation must be included in the program. Some of these can be easily formulated using mathematical functions and included directly into the program, while others cannot easily be expressed in mathematical function, the fuzzy function is the best option to solve this problem. The evaluation function is established to evaluate alternative layout by considering the pipe route, evaluating the relationships between machines, the function of machines, convenience, access, the minimum size of arrangement area and pipe producibility.

- Result of Optimization

The machine arrangements include all machines that are required to be arranged. In this study, 15 representative machines will be evaluation. Figure 2.23 and 2.24 show the arrangement result of this study.

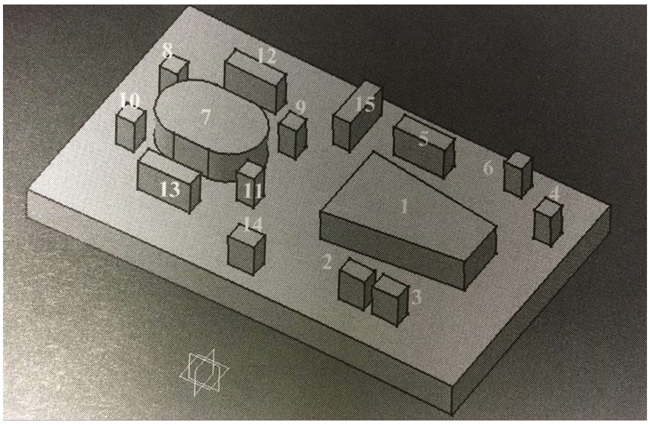


Fig. 2.23 Machinery arrangement in engine room

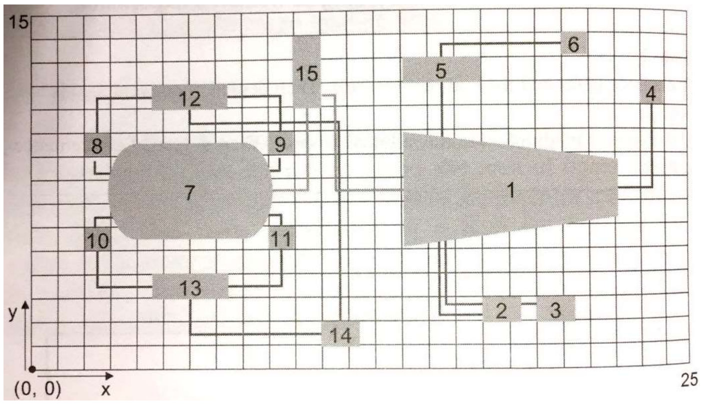


Fig. 2.24 Machinery arrangement including pipe routing

(2) Equipment arrangement design in engine room (2)

- Problem statement

The study on optimization of machinery arrangement and pipe routing using Fuzzy function also proposed by Wu et al. [1998]. They conducted 7 machines arranged and pipes to be routed.

- Data

To confirm the effectiveness of the proposed method, the 7 equipment such: pump, tank, filter, etc. are carried out to be arranged in the engine room area. By using the proposed algorithm, the optimal layout is obtained due to some objectives function.

- Optimization Algorithm

Fuzzy function is adopted to optimized the arrangement of this study. In the evaluation of the arrangement design of a ship, all elements that are involved in the evaluation must be included in the program. Some of these can be easily formulated using mathematical functions and included directly into the program, while others cannot easily be expressed in mathematical function, the fuzzy function is the best option to solve this problem. The objective function of this study is listed in the followings:

1. Maximize the convenience of operation, maintenance for all machines. The degree of convenience for each machine under various conditions is defined by a fuzzy function, as described in the previous section.
2. Minimize the size of the engine room. The size of the required engine room space, defined by RMX and RMY, is to be minimized. RMX is the distance between the lowest-and the highest-x boundaries of the two machines at the minimum and maximum x locations. Similarly, RMY is the distance between the two extreme boundaries of the two machines at the minimum and maximum y locations.
3. Maximize the estimated 'producibility' of all the pipes. Pipe producibility is included as one of the objectives when sequential coordination between MA and PR is required. Therefore, the pipe producibility in MA is calculated based on the estimated pipe length and the estimated number of bends.

- Result of Optimization

The machine arrangements include all machines that are required to be arranged. In this study, 7 representative machines including T-junction will be evaluation. Figure 2.25 shows the arrangement result of this study.

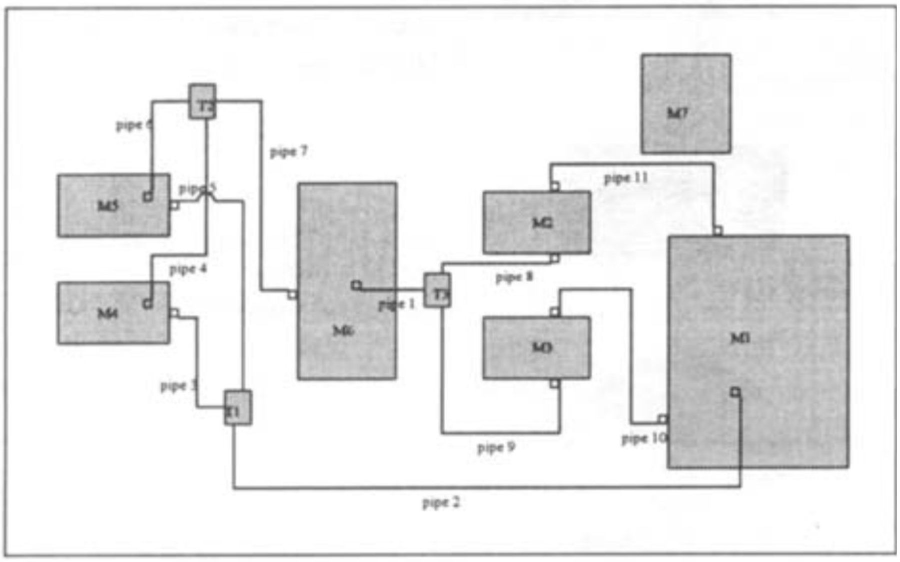


Fig. 2.25 Machinery arrangement including pipe routing and T-junction

2.3 Characteristics of this Study

2.3.1 The explanation of characteristics of this study

This study propose a new concept of the shipbuilding development specifically in the engine room design including piping system. Of course, some references related to this study are described in the previous chapter. However, in this study, have several characteristics that is the originality comparing to the references. The characteristics of this study consists of three important keys, such as:

1. The target ships are various types of series ships
2. The commonness of the modules for all ships is considered;
3. Similarity in the module arrangement for all ships is considered;

The detail of these characteristics will be described in detail to make clear the originality of this dissertation.

(1) Target ships are various types of series ships

In this study, three kinds of series ships with different capacity are carried out. Series ships concept is the new approach of the one of the method to increase the productivity. Series ships concept has many advantages such:

1. Total design time and design cost are smaller than individual ship design concept.
2. The quality is improved due to the minimum of the construction mistakes.

Some related studies of piping design conducted only one ship as their studied. Moreover, several researcher only used some components inside engine room. However in this study, we conducted three series of ships with different capacity. The total of ship for all series is about 100 ships. Figure 2.26 shows the originality scope of the target ship in this dissertation comparing some related studies.

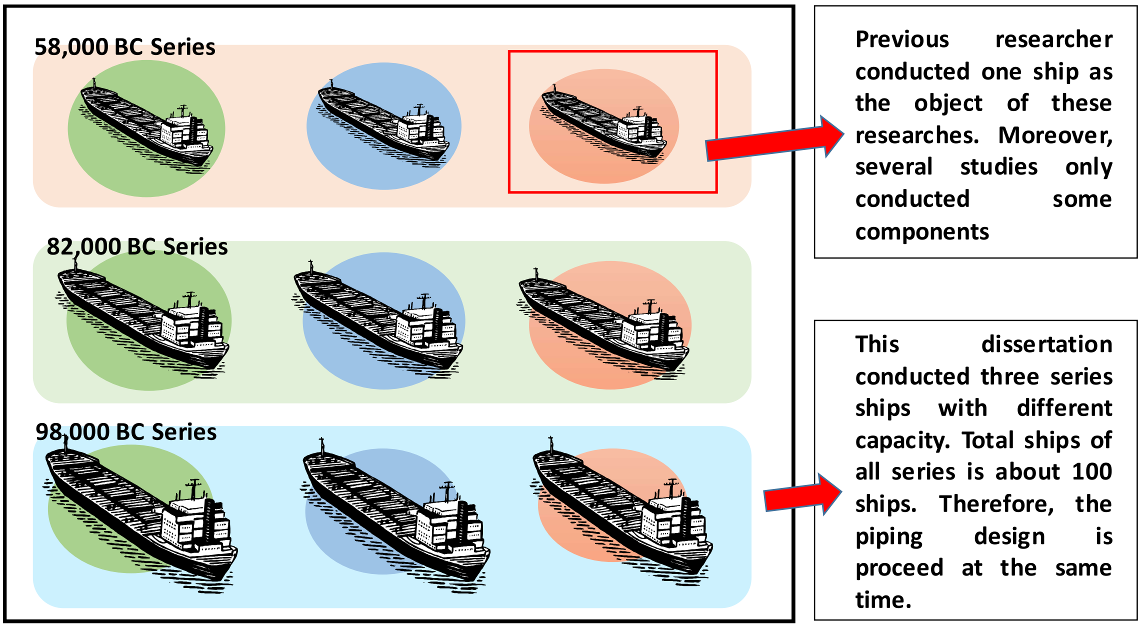


Fig. 2.26 The originality scope of the target ship in this dissertation

The piping design optimization in this dissertation is simultaneously process for all ships. Consequently, the result piping design is the standard design. Therefore, all ships are complied with the design result.

(2) Commonness of the module for all ships

The modularization concept using the DSM is the second originality in this dissertation. Certainly, the modularization concept is not the new method in order to solve the piping design problem, however, in this study the modularization concept is different with the modularization concept in the previous related studies. In the previous studies, generally, module is define as the subsystem of the main engine room components. Consequently, module is define as a functional volume of system unit inside engine room like fuel oil module, sea water cooling module, fuel oil module and so on. However, in this dissertation, the module is define as the group of components with strong connection. Therefore, each system inside engine room like sea water cooling system will be modularized in to several modules. Figure 2.27 shows the difference of the module definition between this dissertation and the previous related studies.

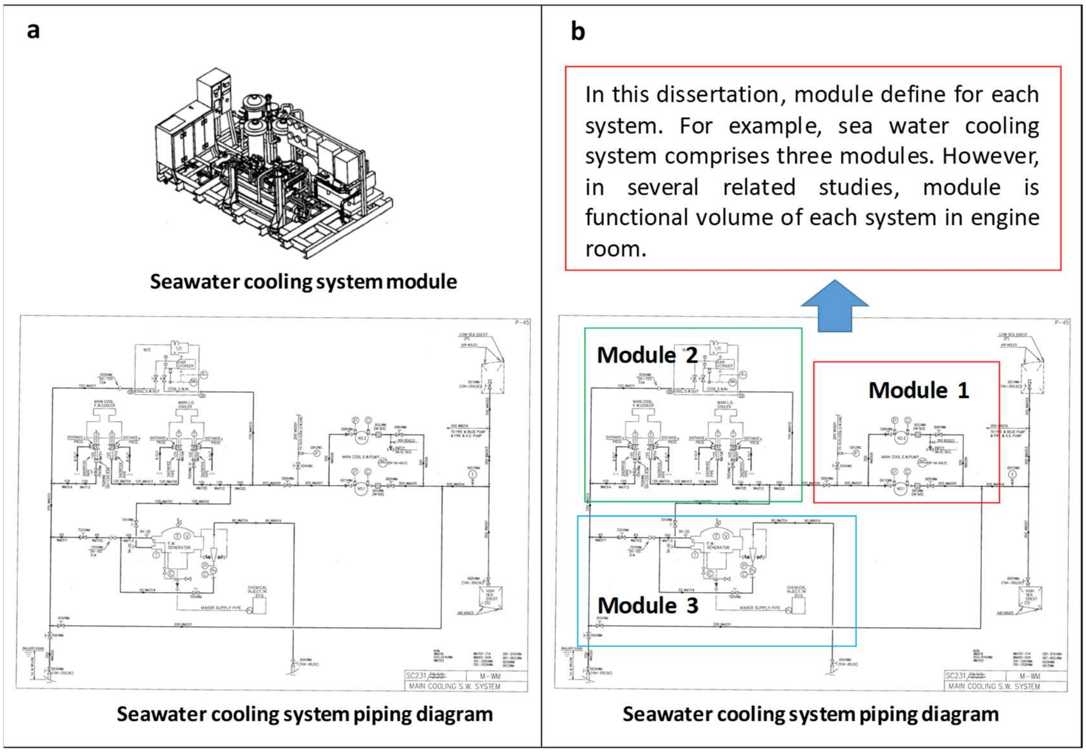


Fig. 2.27 The difference of the module definition

According to the Figure 2.27 (a), some related studies; module is defined as unit of system inside engine room. Therefore, in this case, the example of module is seawater cooling system module, fuel oil module and etc.

However, in this dissertation, module come from the each piping system inside engine room. As illustrated in Figure 2.27 (b), seawater cooling system is modularized into three different modules.

The other originality of this dissertation is that the modularization is proposed for all series ships. In a word, all piping system in 100 ships will be modularized simultaneously. Basically, the piping system for each ship is similar. However, according to the differences of the owner requirements, certain ship has different component in several piping system. Therefore, these components are categorized as optional components. For this reason, the modularization is divided into two kinds; common modularization for common components and optional modularization for optional components. Each series is different in size; consequently the size of component may be different. The differences of components is not considered in the modularization. The most important point in the modularization is compose common module for all ships in all series. In the previous related studies, the commonness module is not considered because the target ship is only single ship or only several components. Figure 2.28 shows the commonness module concept in this dissertation.

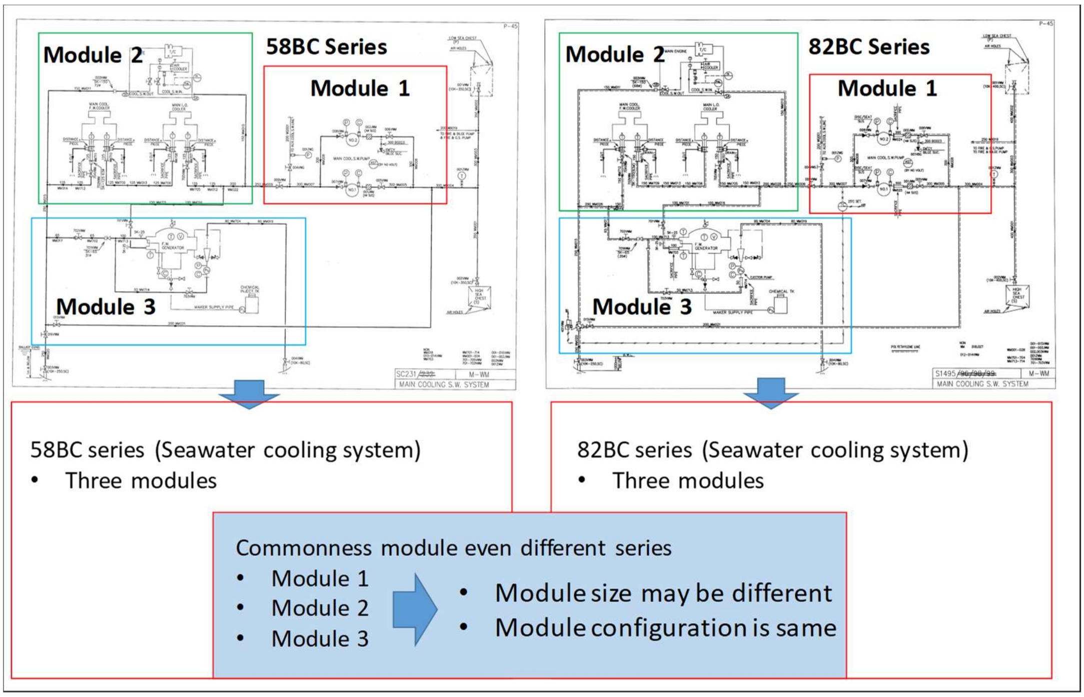


Fig. 2.28 The concept of module commonness

Figure 2.28 shows the commonness of the modules for all ships. In order to compose the commonness module, at first all components for each system in all series are collected in one component relationship data. The components data and connections data are same for all series except for certain piping system in several ships that included the optional parts. Therefore, only for optional parts and its relations data will be modularized into optional module. Only certain ships have the optional modules.

(3) Similarity arrangement of the module for all ships

The third characteristics of this dissertation is making similarity of the module arrangement. As discussed above, commonness module is decided after modularization inconsideration of various series ships. Therefore, all modules should be arranged by considering the optimization and of course similarity position in the engine room area. The similarity is very important to obtain some advantages such: easy in the construction, easy in the installation and easy in the maintenance activities. And also, the similarity arrangement will cut the complexity of arrangement design in all ships. As discussed above, in this study, there are 100 ships as the target ship. What is the complicated design and problem if each arrangement design is different for each ship. Therefore, the similarity arrangement is one of the most important originality in this dissertation.

According to the some related previous studies of arrangement in piping design, the similarity is not considered because the design is executed one by one for each ship. Some references proposed system optimization to arrange module. However, the result of optimized arrangement is only for each ship. In a word, local optimization is obtained. Some different references, in fact, the arrangement is decided without the modularization at first. These studies only focused on the part or component arrangement inside engine room without simplify the complicated of piping system using modularization. In fact, many researchers conducted several components in the optimization arrangement system. In addition, some references decided optimized arrangement of module and or component only in the one deck. However, in this dissertation, all modules should be arranged in three level decks as the real condition of the design from company. The illustration of the similarity arrangement as one of the originality in this dissertation is described in the Figure 2.29 (b).

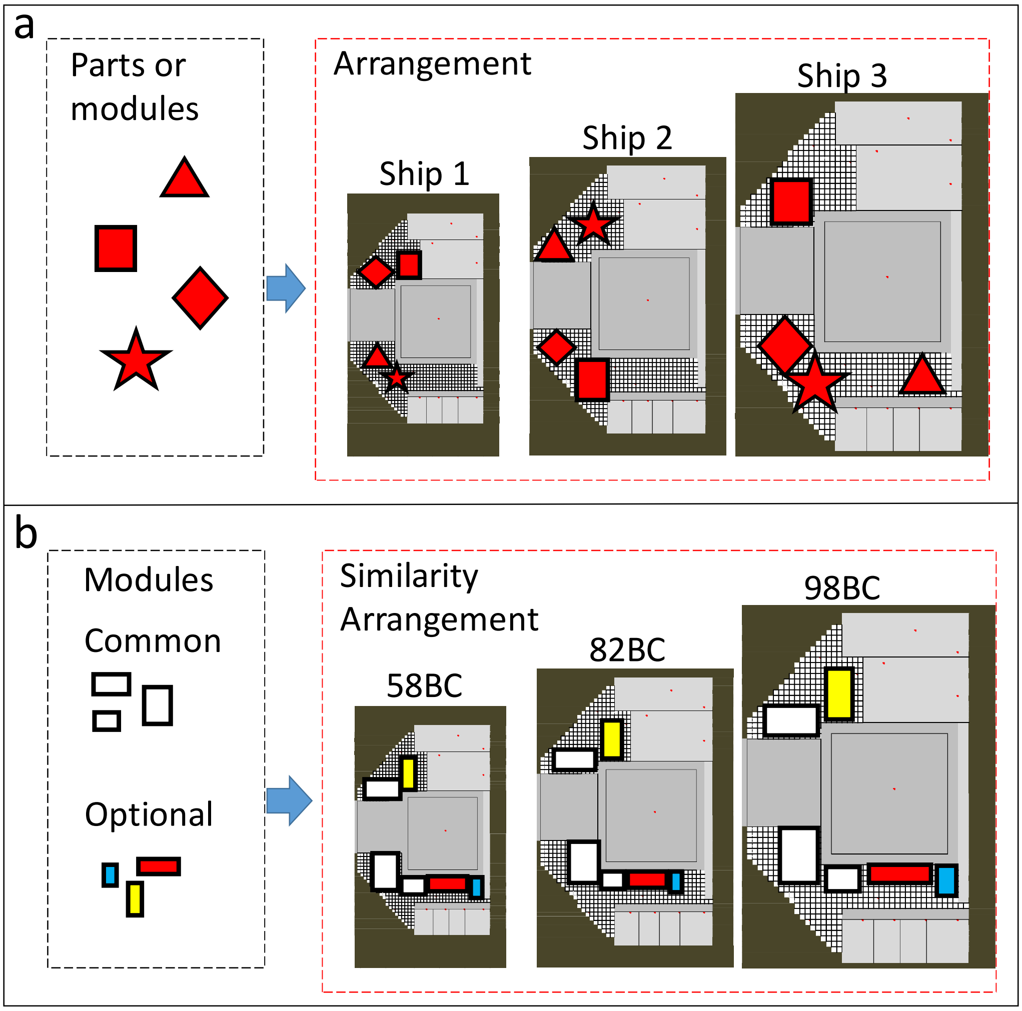


Fig. 2.29 Arrangement concept of related studies (a), arrangement concept of this dissertation (b)

Figure 2.29 shows the comparison of arrangement concept of related previous studies and arrangement concept of this dissertation. In all related studies, the similarity arrangement is not considered because the design is executed one by one for each ship. As shows in the Figure 2.29 (a), some references using modularization at first before make the arrangement, and some other without modularization concept. In a word, some related studies directly to arrange parts inside engine room. However, in this dissertation, the modularization concept is adopted as the first originality and then, similarity arrangement of the module inconsideration of various series ships also considered as the second originality.

2.3.2 Summary of the differences between this study and the references

Figure 2.30 shows the summarized of the characteristics of this study compare with the related studies.

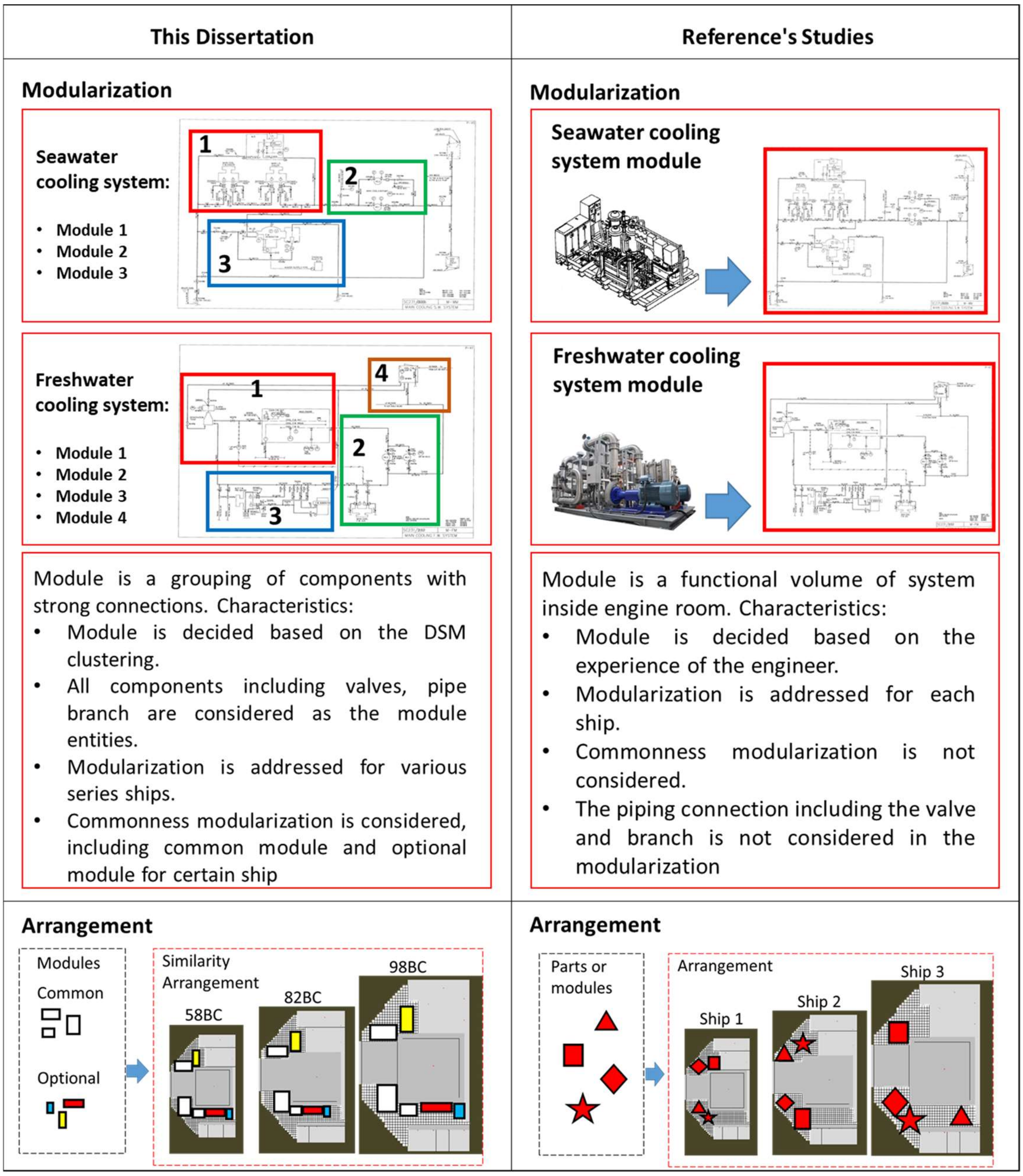


Fig. 2.30 Summarized the characteristics of this study

Chapter 3

Basic Concept

The primary objective of this study is to develop a methodology for arranging engine-room parts through use of the modularization concept with due consideration of various kinds of series ships. To fulfil this objective, the basic concept is divided into the following three problems: problem definition, modularization definition and arrangement definition. In this chapter, the definition of problem including the target ship and the target process of this study is firstly introduced. Since the problem definition is clear describe, it is easy to discuss about modularization definition and arrangement definition comprehensively.

3.1 Problem Definition

3.1.1 Target ship of this study

On its way to becoming successful and competitive on the world shipbuilding market, the shipyard has to build quality, have small cost of production process and short delivery time of the ship. Generally, in the shipbuilding design, individual design concept is the most popular in entire the world. This is because the ship is not similar as mass product like automobile or cellular phone. In case of mass product, the one design might be built for thousands pieces. In the shipbuilding, the ship is categorized as market driven. The owner requires some requirements such as ship mission, capacity, machinery characteristics and other internal system. Every design is just for one ship construction. However, the effectiveness this system is lower than mass product concept.

Nowadays, the concept of sister ship and series ships is introduced in some Japanese shipyards. In case of sister ship, the design of ship were built for more than 1 ship. The ship size and ship characteristic is same for this concept. However, the internal system like piping system might be different. Today, in Tsuneishi shipyard the concept of sister ship change wider. Not only built in the same size, but also the possibility of building similar ship in different size is proposed. This concept called as series ships concept. In the series ships concept, the most important key is create the standard piping system design in the engine room.

Details of target ships, the design of which is considered in the proposed research may be listed as follows.

1. Multiple series of bulk carriers with different capacities are considered. Respective sizes of the series considered herein are handymax (58000 DWT), panamax (82000 DWT), and over panamax (98000 DWT). In this stage, Tsunieshi shipyard will build three kinds of series ships with different capacity. The design of hull and lines might be different for each series because of the different size and capacity. However, in the piping system inside engine room, the specification is not too different. Off course, the owner requires some differences of the component specification in particular ship; however, the configuration of the piping system is almost similar.
2. A single series consists of a significantly large number of ships. In this case, the number of ships that will be built for 3 series is about 95 ships. According to the huge of the total ships, the development of make standard piping system design inside engine room is the best opportunity.
3. The piping system inside the engine room of each ship comprises a fuel system, lubricating-oil system, seawater system, freshwater system, compressed-air system, and steam system. As describe above, the main piping system inside engine room is comprise of six piping systems. Each system is very complicated system because comprise of hundreds parts including their pipe connection.
4. Each ship also comprises different components and arrangements in the piping system based on the requirements of the owner. Typically, the piping system for each ship is most similar. However, the certain part is different according to the difference of the owner requirement. The illustration of the difference of parts and arrangements is illustrated in the Figure 3.2. The part is different for any aspects: items, size and arrangement. Based on the figure, no purifier is installed in 98,000

BC. However in the 82,000 BC series purifier is installed based on the owner requirement. Furthermore, the size of the same part might be different. Finally, the arrangement of the same part also different according to the experience of the designer.

Figure 3.1 shows the target ship of this thesis. Three series of bulk carriers with different size are carried out in this research. The total number of ship in all series is more than one hundred ships with different components and arrangements in the engine room.

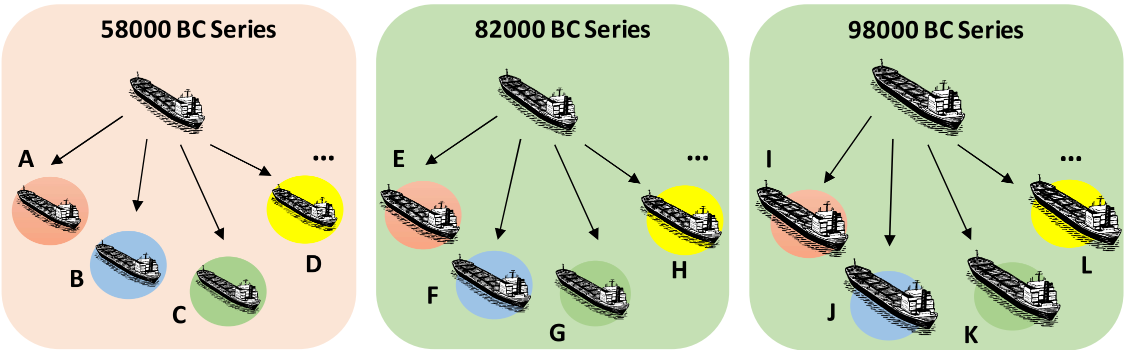


Fig. 3.1 Target ship of this research

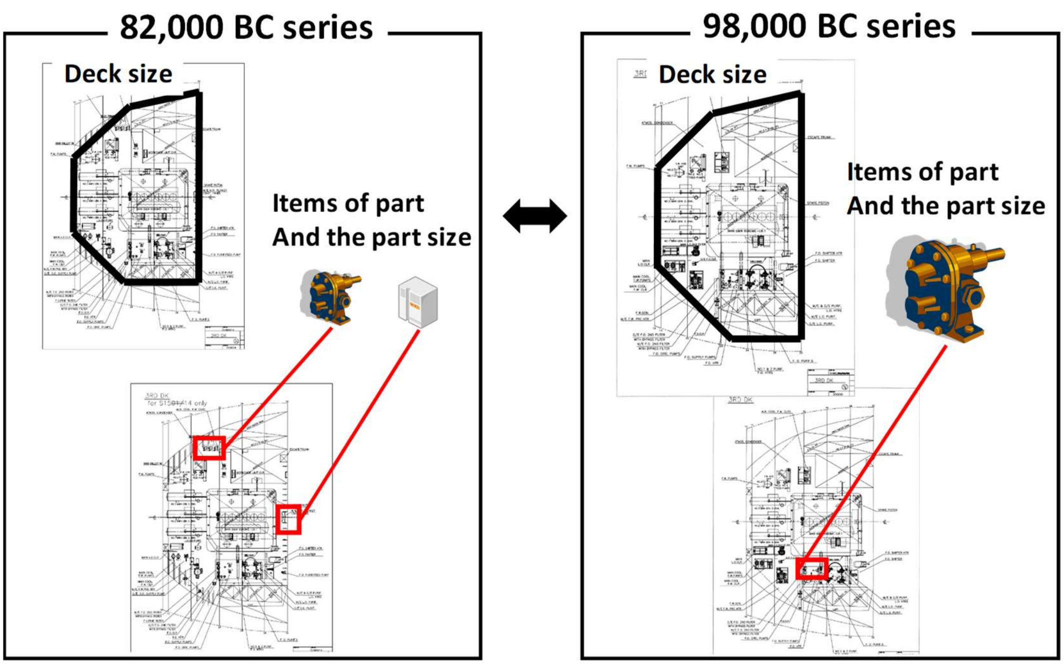


Fig. 3.2 Part difference (items, size and arrangement)

3.1.2 Target process of this study

The piping design process generally consists of following four stages (Figure 3.3):

- Owner Requirements

This refers the information about the owner's requirements or desires that need to be considered to fulfill the subject ship's mission. This information is associated with the existing ship's characteristics and operation. It consists of several aspects such as the principal characteristics, operational conditions, tank and piping system and cargo information.

- Piping Diagram

The piping diagram for each system is examined after designer collects the information from the owner. The piping diagram depicts the correlation of the equipment and the instrumentation. Figure 3.3 (b) shows the main components of the cooling freshwater piping system and flow information.

- Part Arrangements

This stage focuses on the spatial arrangement analysis of all parts. Parts and some equipment inside engine room should be arranged in accordance with the rules and guidelines. However, in the practical, part arrangement is usually performed based on a reference ship data, designer experiences, and the theoretical optimal solution. Part arrangement optimization including some constraint condition is the challenge topic.

- Pipe Routing

Pipe routing design is important to eliminate crossover and interference in the pipe patch. The pipe patch cannot be determined before all the parts are arranged. Figure 3.2 (d) depicts the pipe routing among parts. The pipe routing design depends on the experiences of the designer and the number of parts.

Each ship has different part arrangements in accordance to the above stated flow design. This paper focuses on the part arrangements; therefore, the piping diagram is already fixed and pipe routing is not considered.

The target process of this study is focused on the piping diagram and part arrangement. In the piping diagram, this study proposed the new concept that is modularization concept. Modularization is a grouping process of some parts in the piping diagram based on the strength of the connection of each other. In this study, the definition of part is wider, not only some components like pump, heater, filter and so on but also valve and branch of pipe are considered as the parts. Therefore, each piping system comprise of hundreds parts. Furthermore, all collected parts for each piping system will be proceed using the DSM to obtain the appropriate module.

Since the all parts in the piping system have modularized, then the next step is how to manage the position of all modules in the engine room area. Therefore, module arrangement definition is important to obtain the optimized arrangement. Arrangement is a process to locate the all modules in to the engine room area based on the some constraint conditions and consider the optimization problem. In this study, the engine room for each ship comprise of three level decks. Therefore, all modules should be arranged in the three different decks.

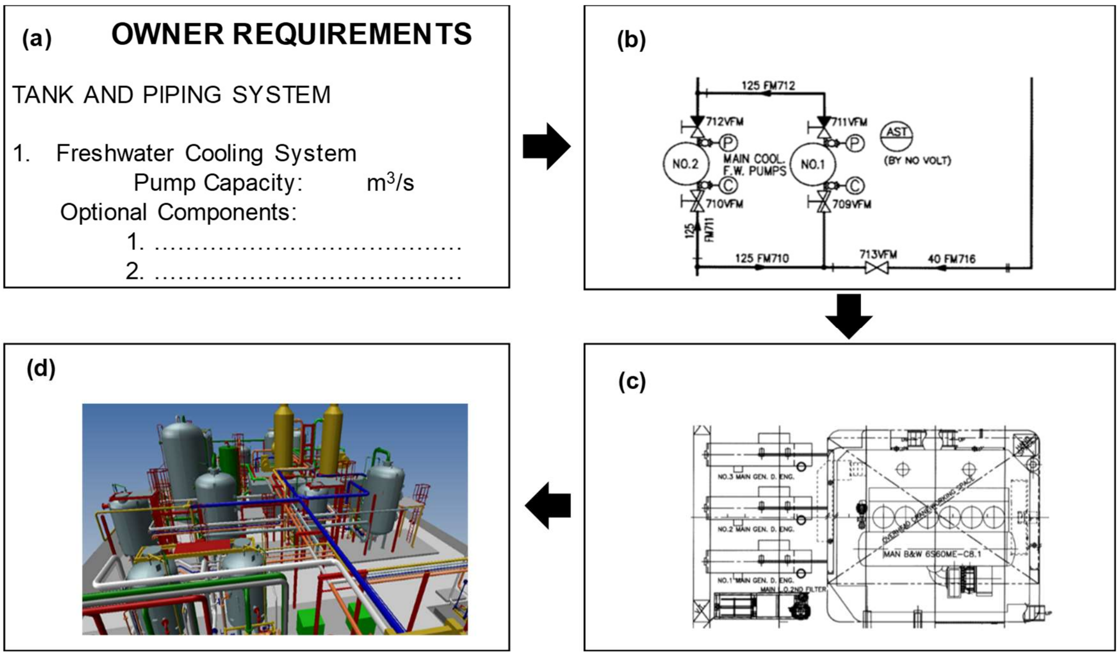


Fig. 3.3 Piping design process

3.2 Module Definition in this Study

3.2.1 Module definition

In this study, modularization involves grouping of parts with a strong dependency into one group. Module is decided based on the collection data of all parts for each piping system. Therefore, the following steps is the illustration of the precondition of the modularization.

- **Decompose**. Break the each piping system down into its constituent elements perhaps through several hierarchical levels. In this case, each piping system consists of four kinds of parts division, such:
  1. Fix part. Fix part is the main part inside engine room that is the position of these are fix based on the company data. The example of fix parts are: main engine, tanks, workshop, generator, boiler, ballast pump, sea chest, etc.
  2. Main parts. Main parts is component in the piping system that is the position is flexible inside engine room. The example of main parts such as: purifier, cool seawater pump, cool freshwater pump, fire pump, bilge pump, cooler, freshwater generator, bilge separator, etc.
  3. Valves. All valves are considered in this dissertation as one of the part division.
  4. Branch of pipe. All branch of pipeline, including T junction or cross junction are considered.

The important point in this stage is only division number 2 through number 4 are considered as modularization. In a word, Fix part is not considered in the modularization. Therefore, module is generated from main part, valves and branch of pipe. In addition, the reason why the fix part is not considered in the modularization, it is because module should be arranged in the optimized position using some constraint conditions. However, fix part is the part with fix position based on the initial data from the company. Figure 3.4 shows the illustration of part division in the piping system.

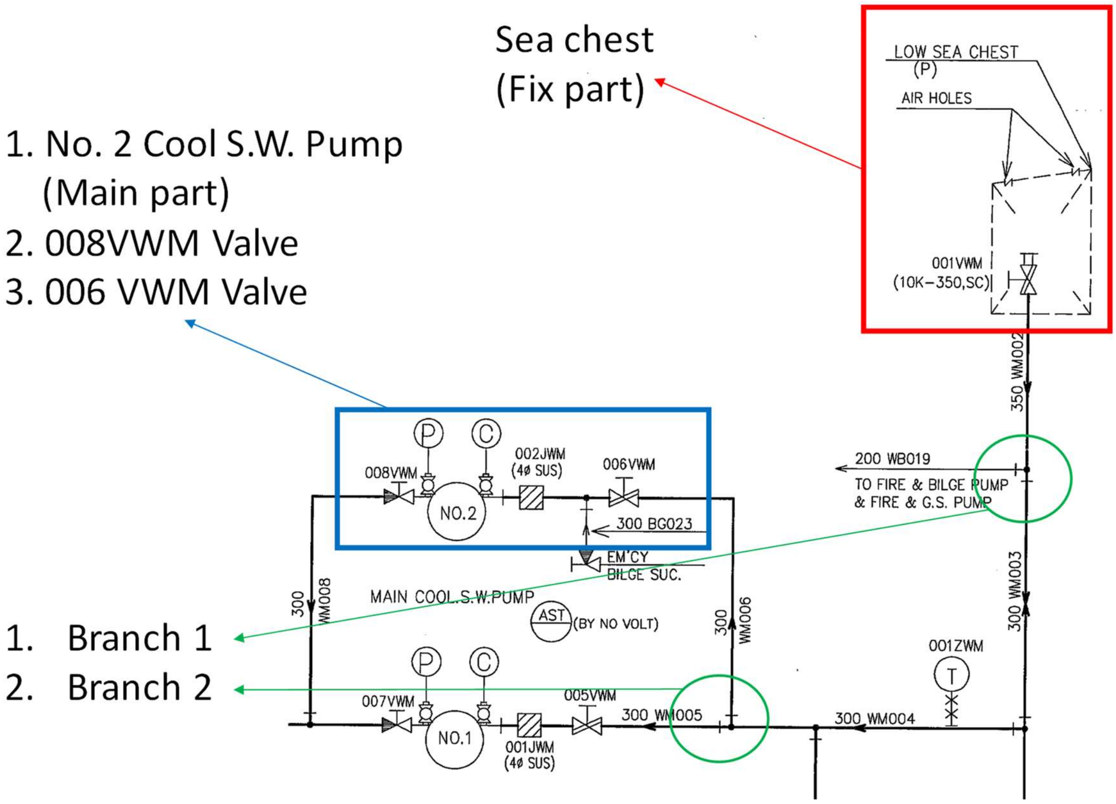


Fig. 3.4 Part division to be collected before modularization

Figure 3.4 shows the procedure to collect all parts in the piping system. At first, all parts for each system are collected into one list of parts in the excel data. Specifically, fix part is shorted from the list because fix part is not considered for the modularization. All parts excluding fix part, subsequent are listed in one excel file.

- **Identify**. Identify the relationships among the parts. This document is very important in order to analysis the possible module generated. For the example, between No.2 Cool S.W Pump with valve number 006 VWM is connected with a pipe which diameter 300 mm (300 WM006). In other example, branch 1 and brach 2 is connected with pipe which has diameter of 300 mm (300 WM004 & 300 WM003).
- **Display**. In this stage, the DSM is adopted to obtain the module. The detail of modularization using DSM is reported in the chapter 4.

In this dissertation, module is grouping of several parts, which has strong interaction. The interaction in this case means the pipe connection with certain diameter. The illustration of module after modularization in this dissertation is depicted in the Figure 3.5.

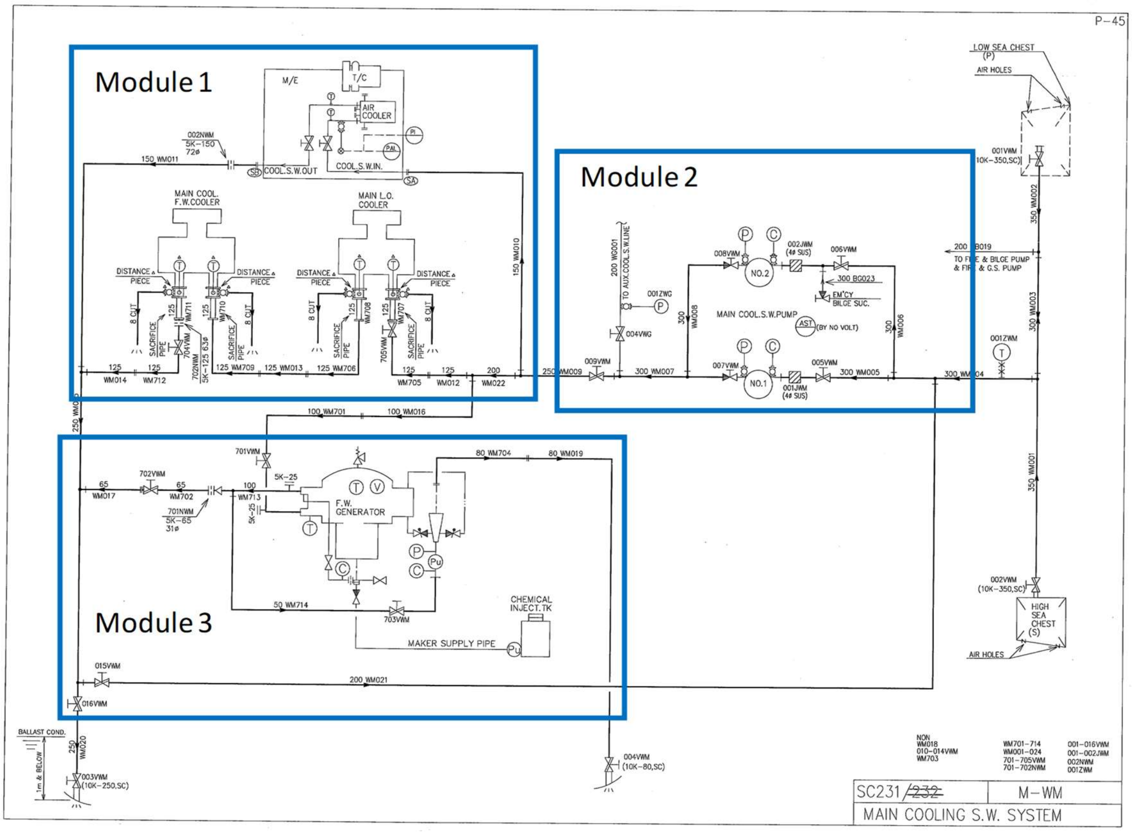


Fig. 3.5 Illustration of module in main cooling seawater system

Figure 3.5 illustrates the result of modularization. In this case, there are 3 modules are generated. Based on this Figure, we can conclude that module 2 comprises of 11 components such as: cool seawater pump no. 1 and number 2, 6 valves and 3 branches of pipe. The detail of modularization procedure in this dissertation is depicted in the chapter 4. Modularization addressed for all piping system. However, each system for all ships should be modularized in one time. For the example, the seawater piping system for all series (100 ships) is almost similar. The differences are occurred in several piping system in certain ship. In the seawater piping system, no optional parts are included in certain ship. In a word, the seawater piping system for all ships is same configuration. The difference may be come from the size of part. However, size of part is not considered in the modularization. Therefore, commonness modularization is possible to addressed in this dissertation. Figure 3.6 shows the piping system that have optional part.

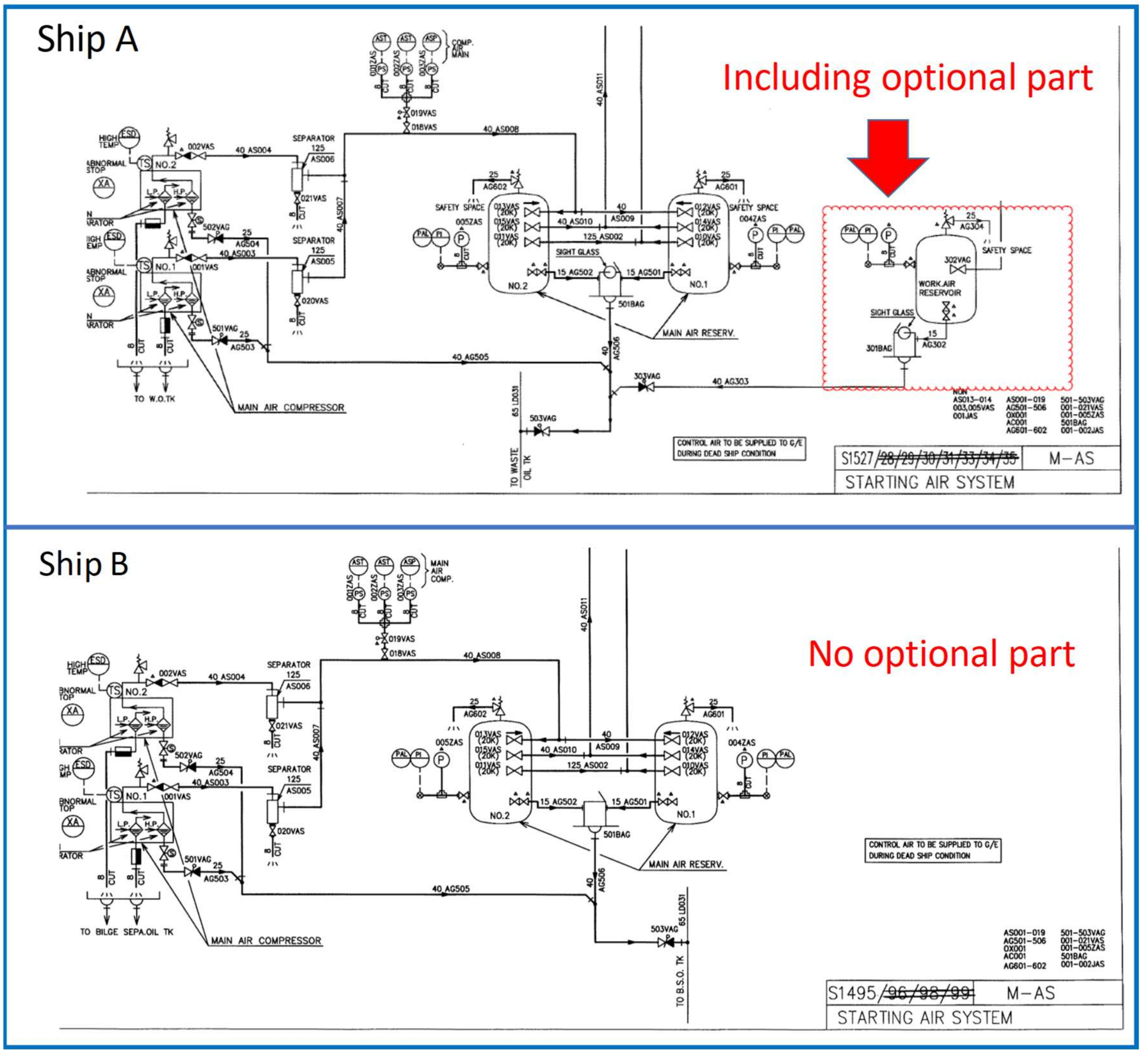


Fig. 3.6 Example of piping system that have optional part

Figure 3.6 illustrates the compressed air system. Ship A is equipped with optional part; work air reservoir. However, in ship B air reservoir is not required. In order to solve this problem, the modularization is proceed separately between common part and optional part. Thus, the commonness modularization is possible to adopt even in some certain ship are equipped with some optional parts.

Subsequent, for more detail about the modularization concept in this dissertation, Figure 3.7 shows the illustration of module configuration of each series.

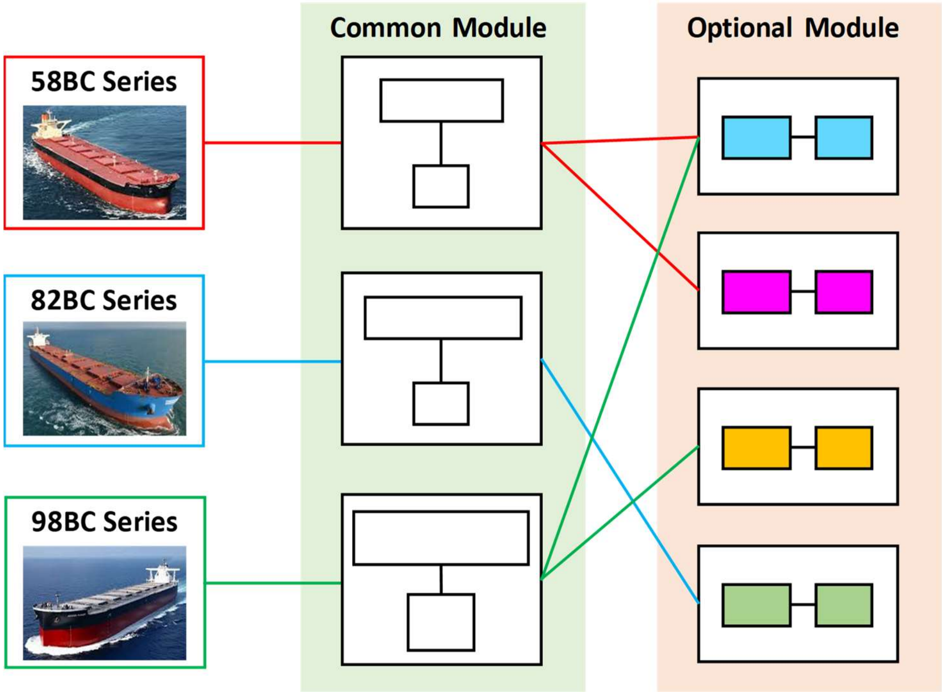


Fig. 3.7 Different module specification of each series

Figure 3.7 shows the illustration of module configuration in all series. Based on this Figure, the common module for each series is same both in total number and in the configuration. However, the optional module may be different for each ship in the same series or for each ship in different series. Moreover, generally some ships are not equipped with optional module. Therefore, the optional module is equipped in the certain ship.

The other illustration is depicted in the Figure 3.8. In this case, three series ships are carried out, such 58BC, 82BC and 98BC. In this example, there are two ships of 58BC series, one ship of 82BC series and one ship of 98BC series. All parts for each ship are collected to make entity (part)-relationship model as described in the figure 3.8. The white entity means common entity and the colour entity is the optional entity. For all ships, the common parts or entities are same. However, the optional part is different for each ship. The modularization for common part and optional part is separately. The red box indicates the common module. Green box is the optional module of ship A, blue box is the optional module of ship C and orange box is the optional module of ship D. The optional module is different for each ship because of the different of the owner requirement.

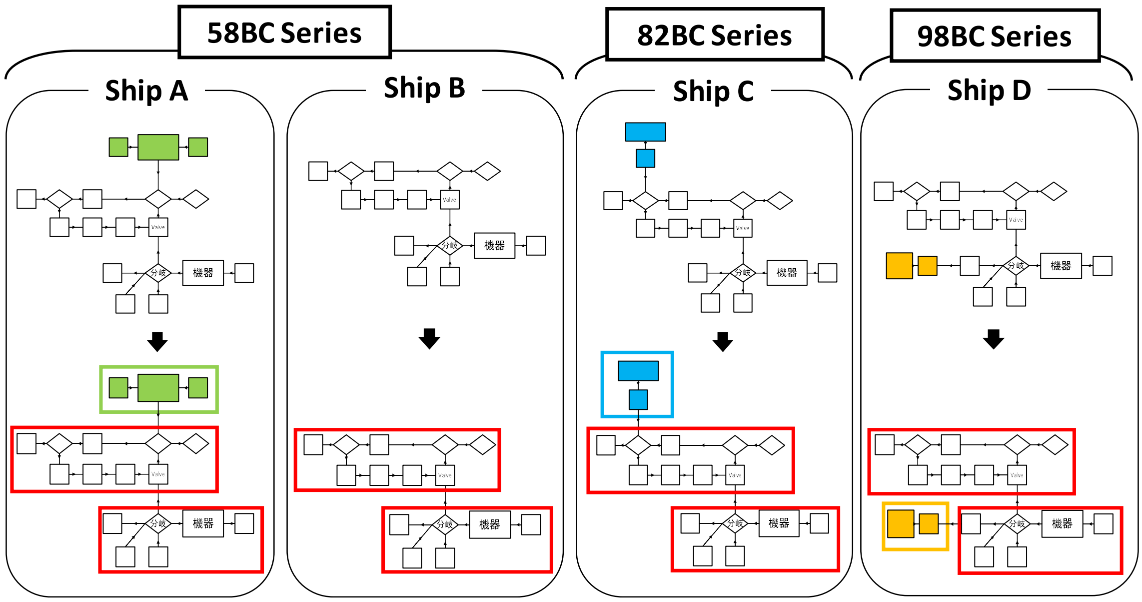


Fig. 3.8 Common and optional module in series ships

3.2.2 Requirements for modularization

In order to realize the modularization definition as discussed above, the requirements for modularization are important. In this dissertation, modularization require 5 points. The requirements for modularization are as follows:

- Module should be defined for a single ship, a series ships, and for various types of series ships.
- Modularization for common parts should be separate from that of the optional parts.
- Based on the owner's requirements, both common and optional modules should be able to change in capacity and size without a change in the module configuration.
- A combination of common modules and optional modules should be possible to obtain a new ship type based on the owner's requirements.

- To use the modularization concept effectively, complex connections should be included in the module. Therefore, connections between the modules should be minimized.

The detailed of each requirement will be described in the followings:

(1) Module should be define for single ship, series ships and for various series ships.

The modularization is started with decompose of the piping system into part definition. Because the each piping system for all ships identic, therefore the modularization is possible to proceed at one time. In a word, the integration of part list including connection data is needed. Exactly, the size of some parts are different for each series. However, module size is not considered in the modularization. Modularization just carry the number of part including the pipe connection.

(2) Modularization for common parts should be separate from that of the optional parts.

Basically, the piping system for all series is similar configuration and number of the parts. However, according to the differences of the requirements from the owner, several ship are equipped with additional part called optional part. Consequently, the modularization for common part and optional part should be separately. Since the modularization is separately, the commonness of dollarization is created easily. Figure 3.9 shows the illustration of modularization of the piping system that equipped with the optional part. Based on this Figure, some information can be collected. First, the optional part just equipped in certain ship. Second, the optional part not upset the common part configuration. Therefore, separate modularization is possible to make the system is simpler.

Figure 3.9 illustrates the module both common and optional in compressed air system. Ship A is equipped with optional part; air reservoir. However, in ship B air reservoir is not required. In order to solve this problem, the modularization is proceed separately between common part and optional part. Thus, the commonness modularization is possible to adopt even in some certain ship are equipped with some optional parts.

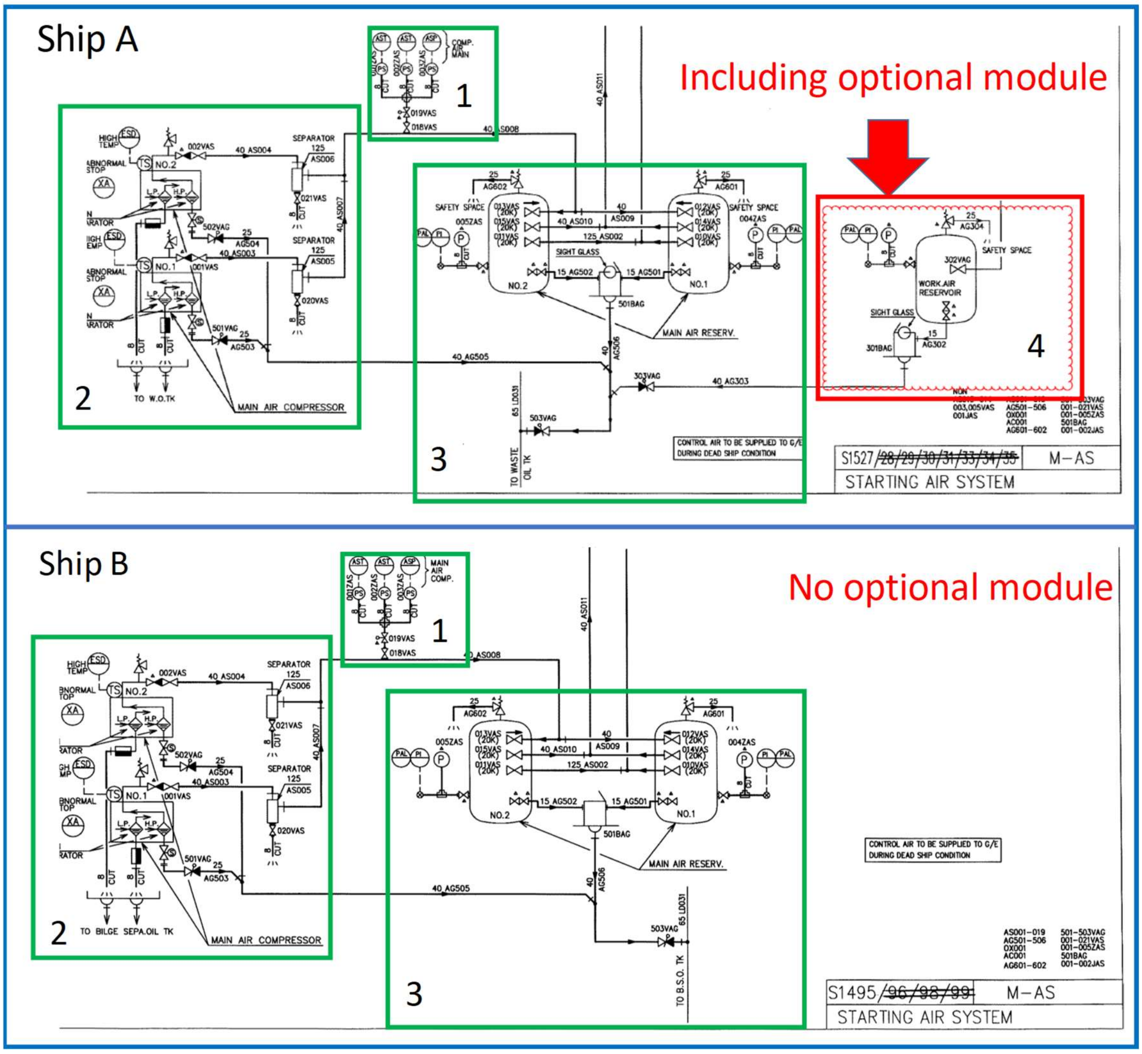


Fig. 3.9 Common and optional module in compressed air system

Based on the Figure 3.9, Modularization for common part and optional part is separately. As the result, common parts are integrated in one list and then after modularization, there are generated three common modules. At the same away, the optional parts are modularized and finally get one optional module. According to the result, the common modules are same for each ship in all series. In addition, optional module is equipped only in certain ship in all series.

(3) Based on the owner's requirements, both common and optional modules should be able to change in capacity and size without a change in the module configuration.

According to the differences of the owner requirements, the change of part capacity and size inside the module is very possible. The change of part properties (capacity and size) will not change the module configuration. For the example, figure 3.9, there are 3 commons module. Module number 2 is the main air compressor including some valves and pipe branches. Module number 3 is main air reservoir including some valves and pipe branches. The configuration is: module number 2 is connected with module number 3 with one pipe (40 AG505). For example, in existing condition, the capacity of air compressor is 15 CFM (cubic feet per minute). And the size (dimension) of compressor is 2 m x 0.5 m x 1 m. When owner requires to change the compressor capacity into the 20 CFM and change the size into the 2 m x 0,8 m x 1,4 m, the configuration of module number 2 is not change. The connection between module number 2 and module number 3 also is not change. However, if the configuration is changed based on the requirement from the owner, the module will be changed. This concept is also adopted in the optional module.

(4) A combination of common modules and optional modules should be possible to obtain a new ship type based on the owner's requirements.

Since the common modules and optional modules are defined, the obtained new ship is possible. Owner just make the combination of available common modules and optional modules. For example, based on the Figure 3.9, it is possible to create new piping diagram with the combination of three common modules and one optional modules. For the example, new piping diagram comprises of module number 2, 3 and 4.

(5) To use the modularization concept effectively, complex connections should be included in the module. Therefore, connections between the modules should be minimized.

The last requirement of the modularization is solved with Figure 3.9. Based on the Figure 3.9 module number 2 and number 3 are consists of complicated pipe connection inside the module. In the module number 2 there are 15 pipe connections, then module number 3 consists of 20 pipe connections. However, module number 2 is connected with module number 3 by one pipe connection.

3.3 Arrangement Definition in this Study

3.3.1 Arrangement definition

Initial ship design of engine room is usually performed based on preceding design data such as reference ship data, theoretical optimum solutions, requirement items and design constraints. And the designed data are used for the next design stage. Moreover, designers modify the layout under consideration of equipment performance analysis and the evaluation of equipment operators. Finally, an optimum layout is selected after evaluation under designer's knowledge and experience.

In ship building, arrangement design of the part in engine room deals with the selection of the most appropriate and effective arrangements that will allow a greater working efficiency. Developing part arrangement is an important step because of the impact of the layout on the operation, repair, and maintenance. Because of the complex and precise nature of the part arrangement layout, the optimization procedures such heuristic, neural network, genetic algorithm is needed.

Basically, part arrangement should be designed to maximize the function of the part and the system that are arranged in the space. In the design process, many criteria must be considered such as how to effectively use people, part, space, energy, how to minimize capital investment, and how to ensure the ease of repair and maintenance.

The arrangement definition in this dissertation is make the module placement inside engine room area controlled by some constraints. In this case, all modules should be arranged in three level decks of engine room area. Figure 3.10 shows the target area of module arrangement.

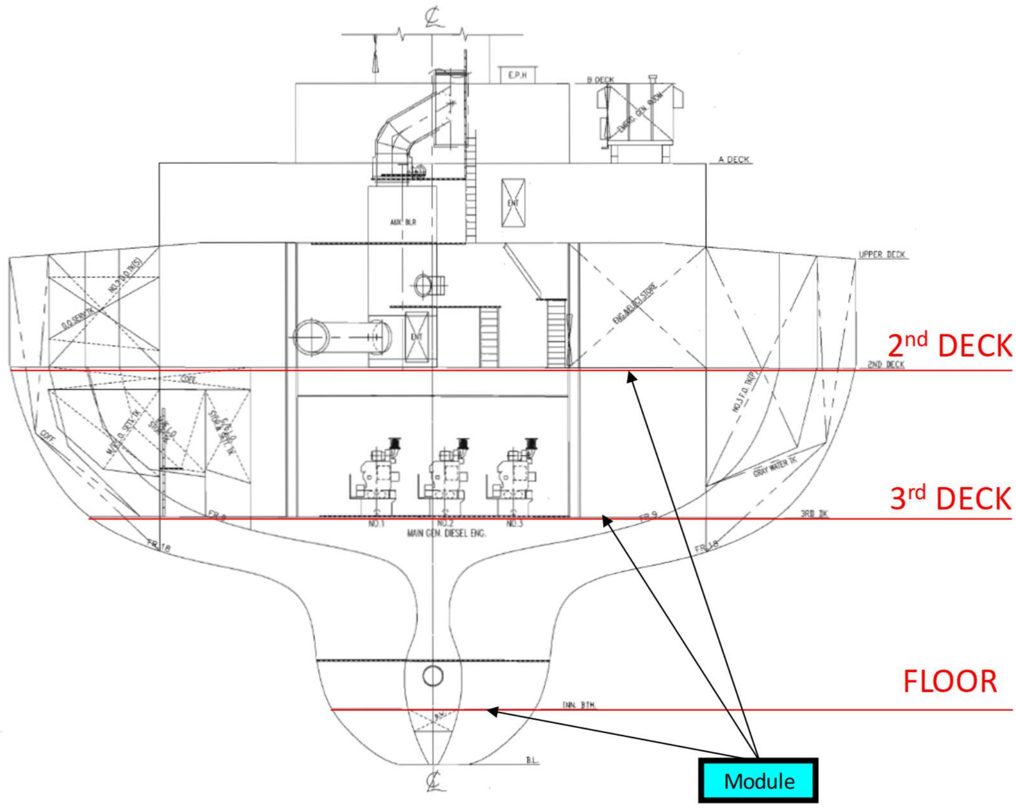


Fig. 3.10 Target deck area of the module arrangement

Figure 3.10 shows the three level decks of the target ship. Both common modules and optional modules should be arranged in these decks, considering the optimized configuration. Certainly, the deck size and module size may be different for each series. However, using the commonness modularization concept, the arrangement of all modules would be easy to meet the optimized arrangement. On the other hand, according to the series ships is the target ship in this dissertation, therefore, create standard design of module arrangement is the most important besides the minimization of the cost of pipe connection. The detail of the arrangement process is depicted in the chapter 5.

3.3.2 Requirements for arrangement

Following the arrangement definition process, the defined modules are arranged inside the engine room. This process has been termed as the module arrangement problem. Some points should be considered, such as:

- Various constraints such as the space requirement for maintenance, area for fixed components, etc. should be considered.
- Similarity of arrangements should be considered for a single ship, series ships, and for various types of series ships.
- Pipe costs should be minimized with respect to the pipe length, diameter, material, etc.

The detail of the requirements for arrangement is described in the followings:

(1) Various constraints such as the space requirement for maintenance, area for fixed components, etc. should be considered.

A design that allows for an appropriate use of space ensures an efficient and convenient working space that enables the ease of operation, maintenance, and repair of machines. If a some parts inside module is to be used often and requires frequent inspection, there should be more space within which to easily operate the part. Conversely, if the part is infrequently used and inspected, then only the minimum space is required. On the other hand, the area for fix components should be pointed. Area for fix component such as main engine, tanks, generator, workshop and etc., is not allowed to arrange modules. The possible arrangement area is the free deck area excluding area for some fix parts and area for maintenance. Figure 3.11 is the illustration of 3rd DECK area in the engine room.

Figure 3.11 shows the actual design of 3rd deck area in engine room. Based on this Figure, the area is divided into three areas; area for fix pars, area for maintenance and area for module arrangement. The area for module arrangement is highlighted with blue colour. All modules should be arranged in the arrangement area. The constraint data such as area for fix parts is decided by the designer from the company. Therefore, in this dissertation, the constraint is fix set by the company. The detail of deck area is depicted in the chapter 5.

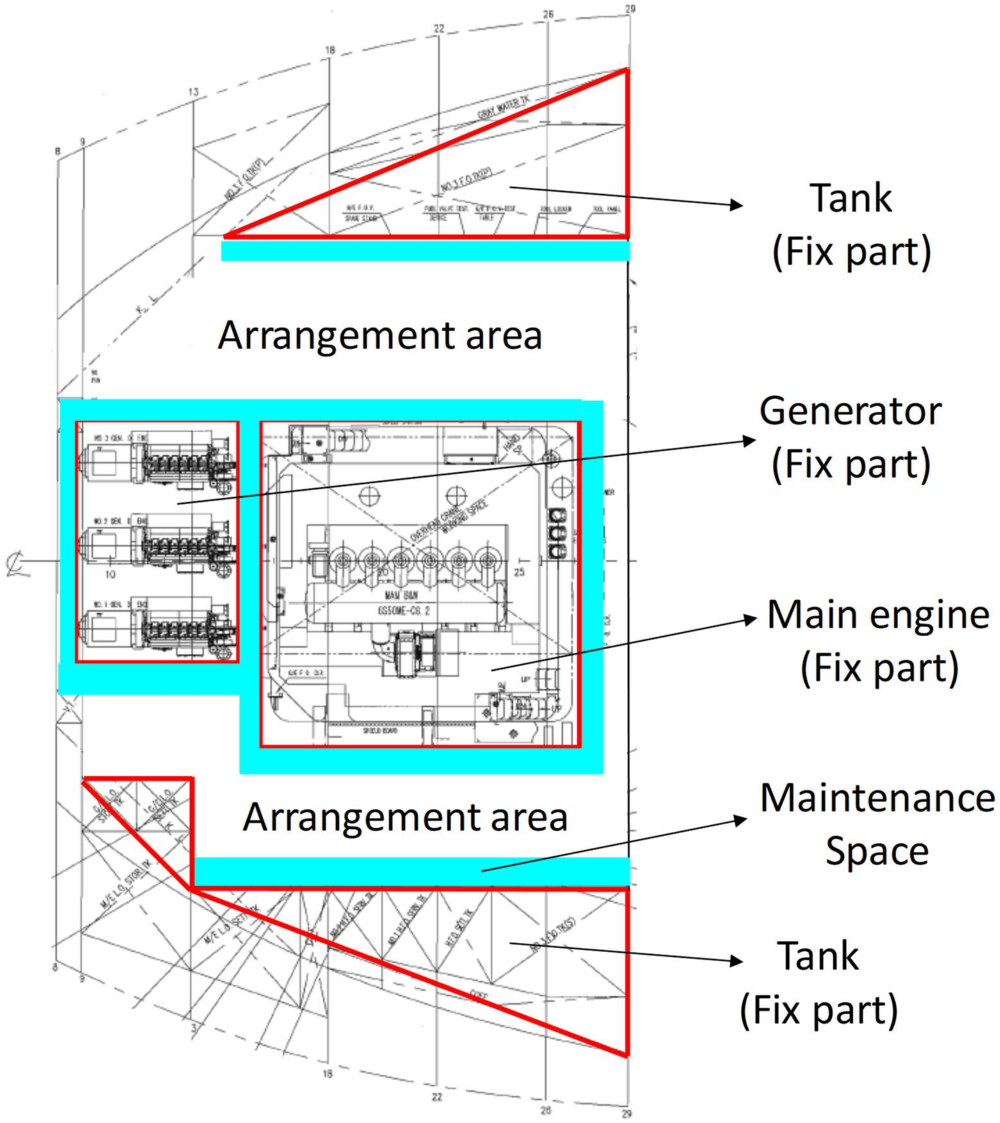


Fig. 3.11 3rd DECK area of engine room

(2) Similarity of arrangements should be considered for one series ships, and for various types of series ships.

Since module arrangement consider the some constraints condition as denoted in the previous chapter, making standard pattern of module arrangement also need to be considered. In a word, if the module arrangement is executed one by one, the result of module arrangement should be different for each ship. Therefore, designer need compose 100 design of arrangement. As described in the chapter 2, the similarity arrangement is one of the several originalities of this dissertation, therefore, similarity arrangement should be considered before create the optimization program. Similarity arrangement is possible way to obtain optimized arrangement in term of standard design of the arrangement. The detail about the how to make similarity arrangement in various series ships is described in the chapter 5. However, simple illustration of similarity arrangement is depicted in the Figure 3.12.

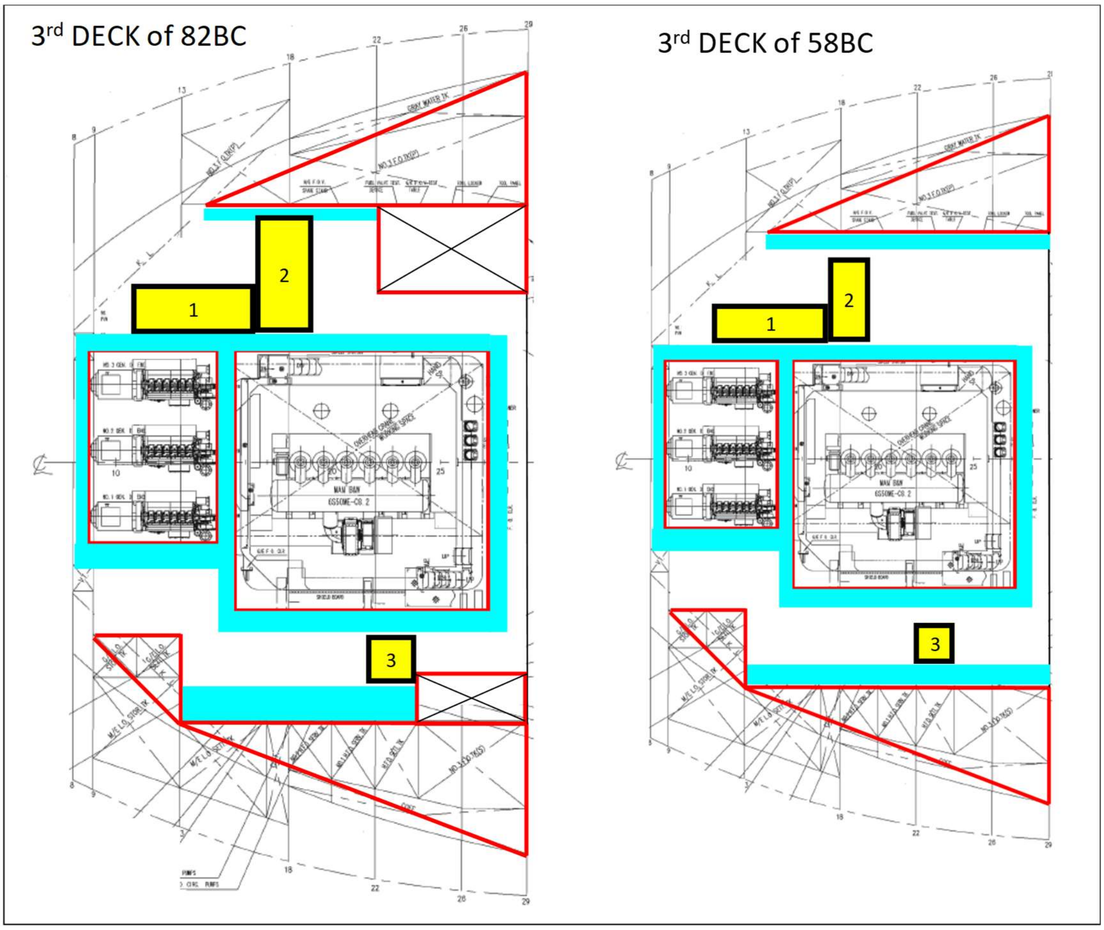


Fig. 3.12 Similarity arrangement in 3rd DECK

Figure 3.12 shows the illustration of similarity arrangement. Certainly, the deck size and module size between 82BC series and 58BC series are different. However, the arrangement for both series should be similar. The similar arrangement has several benefits such standardized design for all ships, decrease the cost and design time.

(3) Pipe costs should be minimized with respect to the pipe length, diameter, material, etc.

The last requirement is the arrangement design should have the minimized pipe cost. Pipe cost is depend on the pipe length, pipe diameter and pipe material. Generally, the pipe cost is entirely affected by the position of the modules. The pipe cost calculation is not simple as the calculation of pipe length between two points. There are very complicated connection between part in the piping system. However, using the modularization concept, one of the requirements is that complicated pipe connection should be inside in the module and connection between module is minimized. In a word, using modularization concept, the pipe length should be shorter than without modularization.

However, in this dissertation, even the concept of modularization is adopted, the pipe length connection between modules should be minimized. In order to solve this problem, the cost of pipe should be considered as the one of the objective function in the arrangement optimization program.

Chapter 4

Modularization

4.1 Overview of Modularization

As the global industry heads into 21st century, companies have started thinking in terms of product platforms with the main objective of shortening development lead times and increasing commonality between products. With a modular product platform structure, a set of module is created with which, trough different combinations, a great number of final products can be built. Modularity aims at increasing efficiency by reducing complexity. The modular approach implies building an optimal product assortment that takes into consideration development, design, variety, manufacture, quality, purchase, and after-sales service.

In the ship piping design, the modularization method is adopted in order to reducing the complexity and making the commonness design. All piping system are modularized to obtain the standard module. The output of this process is in the form of a common module in all piping systems.

According to the development of modularization in automobile industry, nowadays the modularization not only addressed in one type of car but also conducted several types of cars. Therefore, the modularization of piping system inside engine room should be wider. By adopt this concept, the modularization of piping system is possible to develop in the series ships concept. Modularization in series ships concept has several advantages such as: commonness of piping design in several series ships, minimized the design cost, simplify the construction, decreased the lead time, improve the construction quality and etc.

The detail of the modularization in this dissertation is explained in the following chapter.

4.2 Modularization Method

The overview of modularization was explained in the previous chapter. Here, detailed of modularization will be described. In this study, the module definition is executed by the following five steps. This section discusses the details of each step.

4.2.1 Piping diagram

First, the piping diagram of all systems and for all series ships is required to define the module. In this study, the fuel system, lubricating oil system, seawater system, freshwater system, compress air system, and steam system are considered as the piping system.

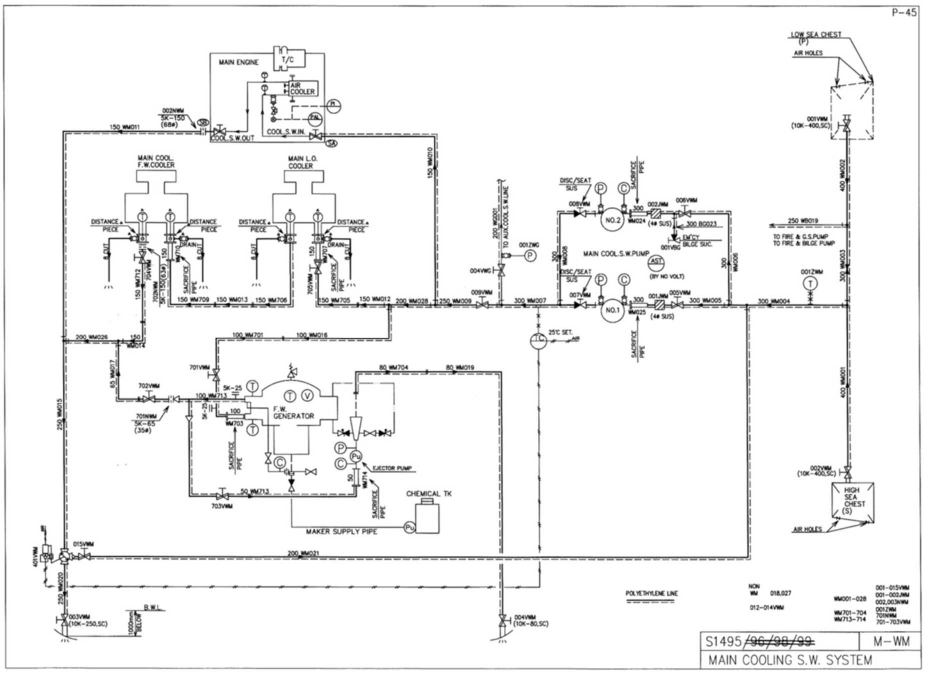


Fig. 4.1 Part of main cooling seawater system of 82BC series

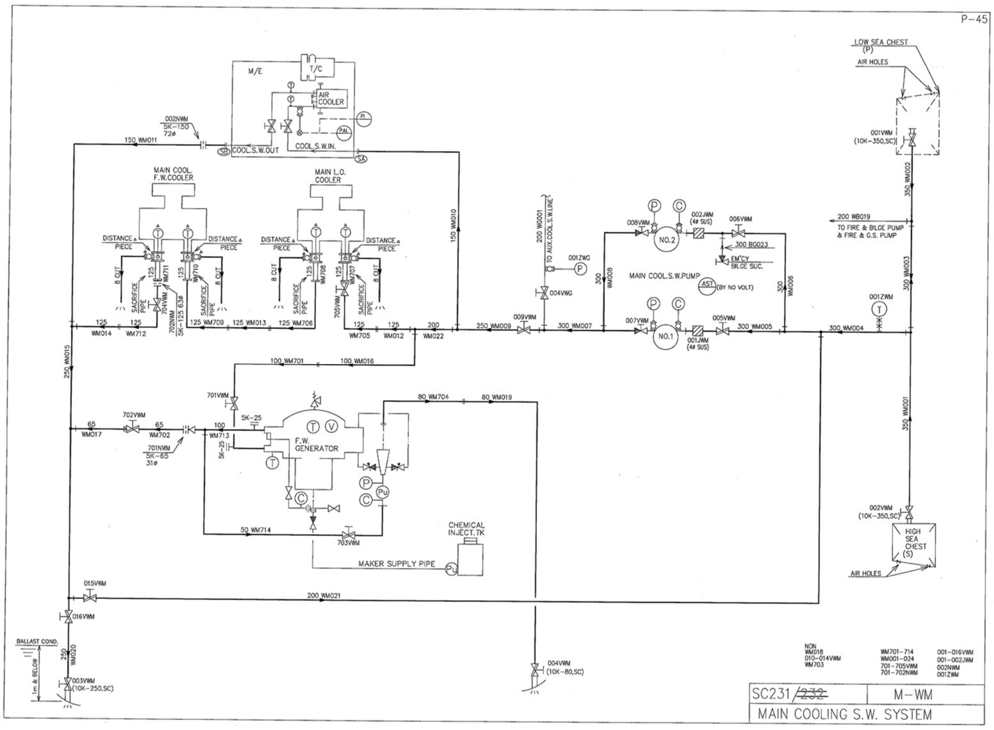


Fig. 4.2 Part of main cooling seawater system of 58BC series

Figure 4.1 shows the part of seawater system of 82BC series. Figure 4.2 shows the part of seawater system of 58BC series. These figure looked similar both the pipeline and the number of parts. However, the size of several parts may be different. In the main cooling seawater system, all parts are common parts. It can be said that, there is no optional part.

4.2.2 Entity-relationship model

To establish relationships between the various parts, this study uses the entity-relationship model (E-R model). The E-R model graphically represents the logical relationships of entities (objects). The model was first proposed by Peter Pin-Shan Chen of Massachusetts Institute of Technology in the 1970. In E-R modelling, the objects are represented by an entity, a relationship, and attributes (Figure 4.3); they can be defined as follows:

- An entity is a thing that exists either physically or logically.
- Relationships denote the manner in which the entities are related to one another.
- Attributes are the properties of entities.

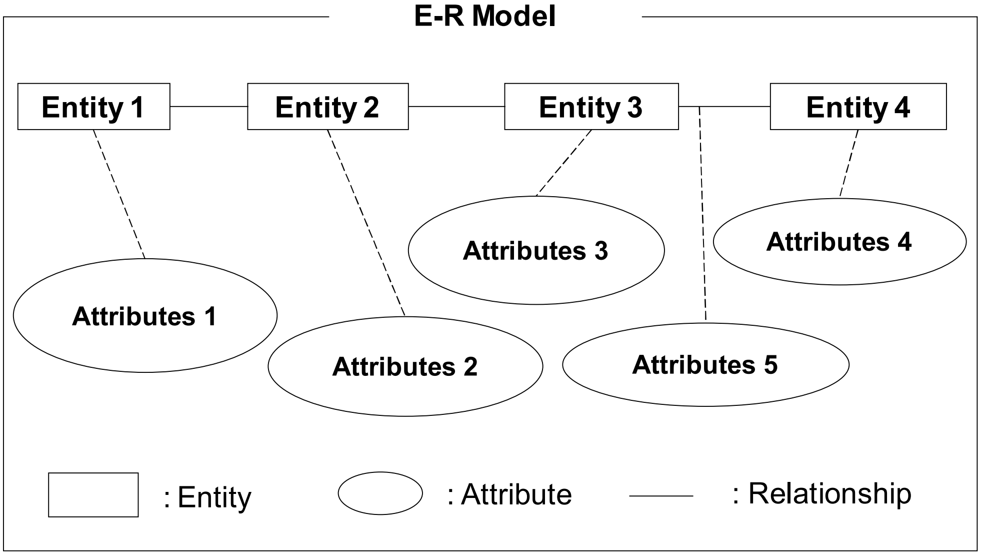


Fig. 4.3 Entity-relationship model

4.2.3 Entity-relationship model for each ship

In this research, the piping diagram is expressed by entity-relationship model. The entities are: the cooler, heater, purifier, filter, etc. The valve and branch are also considered as entities. Then, a relationship is the pipe between the entities. Finally, the flow capacity, heating value, part size, pipe diameter, etc. are considered as attributes. E-R model is composed for each piping system. Therefore, six E-R model are composed for each ship. Figures 4.4(a) & 4.4(b) depict the E-R model of a simple piping system. The entities are represented by the purifier, pump, cooler, generator, heater and filter. The common entities are highlighted with yellow colour and the optional entities are highlighted with green colour. The following attributes of each entity in ship 1 are depicted as well: purifier capacity (450 m^3), pump capacity (500 m^3), cooler capacity (500 m^3), generator power (500 kW), heater heating value (9000 kJ) and pipe diameter (125 mm). The relationship between the entities is represented by a pipe connection. The straight line in the figure is the pipe connection among the entities.

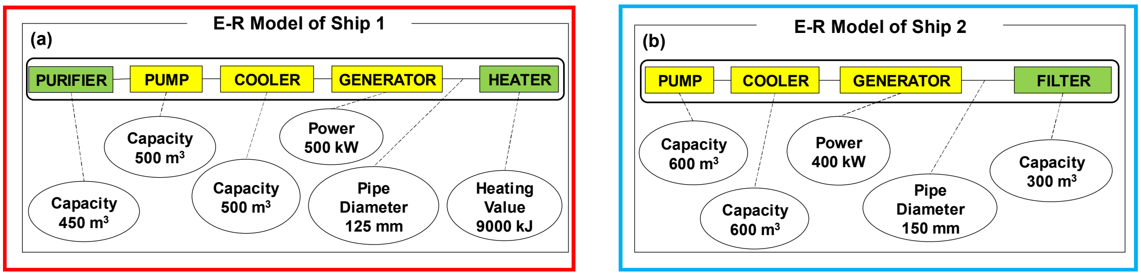


Fig. 4.4 Entity-relationship model for each ship

4.2.4 Entity-relationship model for all series

Subsequent to the generation of the E-R model for each ship, the E-R models are integrated into a single E-R model with specific focus on entities and their relationships. Figure 4.5 shows an example of such an integration. In Figure 4.5, although the attributes are different, the entities and relationship are the same. The entities, in this case, are estimated to be similar; therefore, similar entities and relationships are integrated into a single entity or single relationship. Thereafter, the entities and relationship are classified into the following two types.

- Common entities and relationship: these entities and relationship are used in all types of ships. In this case, the pump, cooler, and generator are the common entities.
- Optional entities and relationships: these entities and relationship are used in a few of the ships, i.e. a series of ships, or ships for certain owners. In this case, the purifier and heater are the optional entity in ship 1 and the filter is the optional entity in ship 2. Integration of E-R model is executed considering the requirements of each ship.

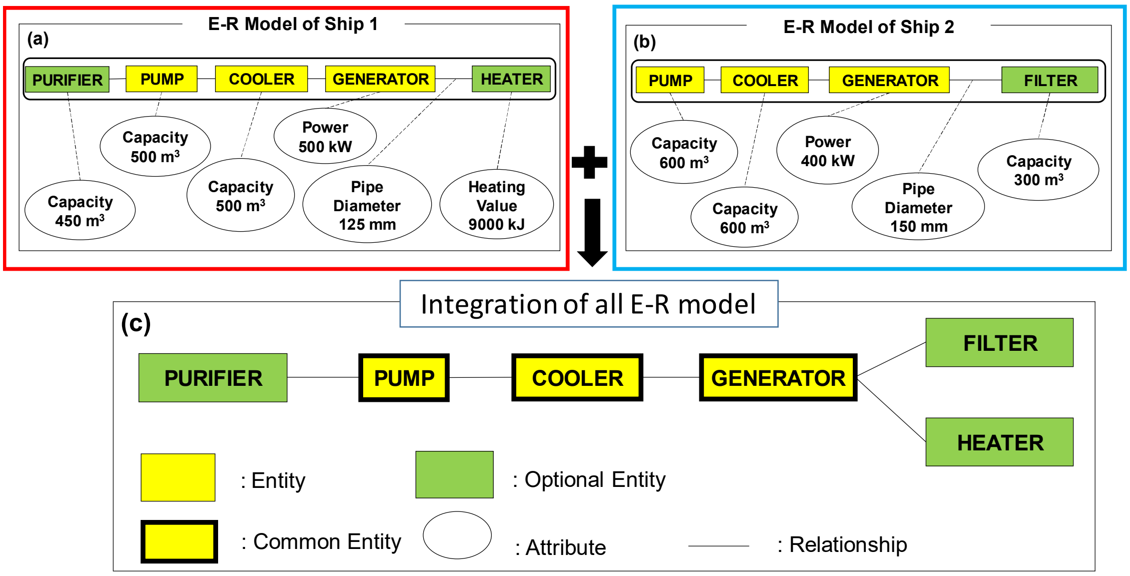


Fig. 4.5 Integration of all E-R model

4.2.5 Matrix representation by DSM

(1) Overview of DSM

DSM is a network modelling tool used to represent the elements in a system and their interactions. DSM is particularly well suited to applications for developing complex engineering systems and is currently being used primarily in the area of engineering management. On the horizon, however, is a much broader range of DSM application addressing complex issues in health care management, financial systems, public policy, natural sciences, and social systems.

The DSM is represented as a square N x N matrix and the interactions among the set of N elements are mapped. DSM has been effectively used to model several types of systems. In the product architecture, the DSM elements would be the components of the product and the interactions would be the interface between the components (Eppinger and Browning, 2012; Lindemann et al., 2009; Kamrani and Salhieh, 2002). Depending on the type of system being modelled, DSM can represent various types of architectures. For example, to model a product's architecture, the DSM elements would be the components of the product, and the interactions would be the interfaces between the components (Figure 4.6.a). To model an organization's architecture, the DSM elements would be the people or teams in the organization, and the interactions could be communications between the people (Figure 4.6.b). To model a process architecture, the DSM elements would be the activities in the process, and the interactions would be the flows of information or materials between them (Figure 4.6.c). Thus, the DSM is a generic tool for modelling any type of system architecture.

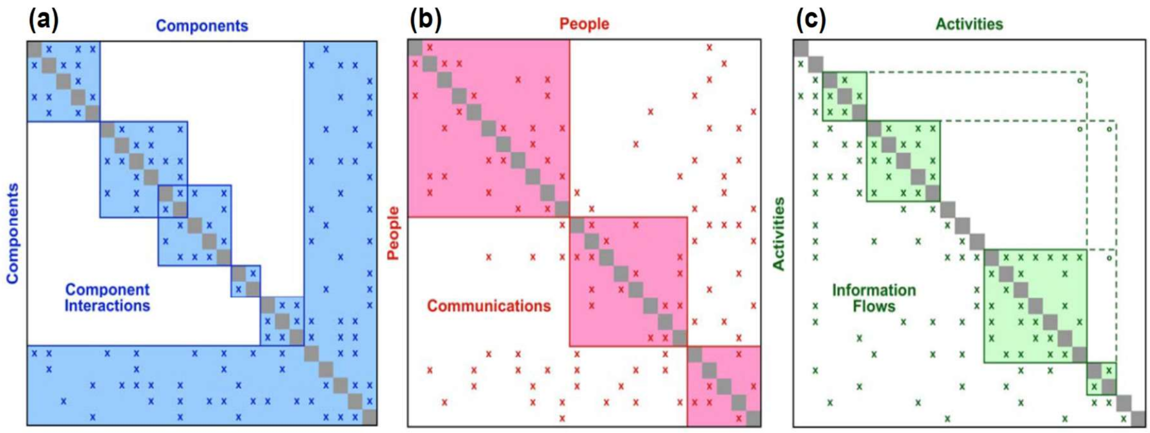


Fig. 4.6 Three primary types of DSM

Compared with other network modelling methods, the primary benefit of DSM is the graphical nature of the matrix display format. The matrix provides a highly compact, easily scalable, and intuitively readable representation of a system architecture. Figure 4.5.a shows a simple DSM model of a system with eight elements, along with its equivalent directed graph (digraph) representation in figure 4.5.b.

In the simple DSM example shown in figure 4.7.a, the six system elements are labelled A trough F, and have labeled both the rows and columns A trough F accordingly. Reading across row A, for example, we see that element A has inputs from element C and vice versa, represented by the X mark in row A column C and row C column A.

(a)

	A	B	C	D	E	F
A			X			
B					X	
C	X			X		
D			X			X
E		X				
F				X		

(b)

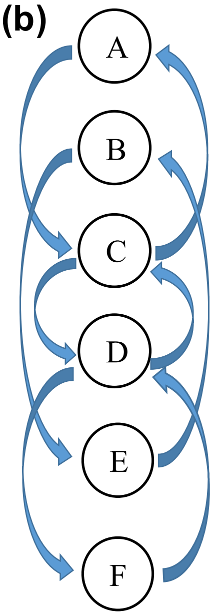


Fig. 4.7 The binary DSM (a) and the digraph (b)

DSM has been used by number of researchers and practitioners for product architecture analysis. Depending on the context or author, these DSM have been given many different names, including product architecture DSM, product DSM, and component-based DSM. In all of these cases, this type of DSM model represents the components comprising a product and the relationships between them. Using product architecture DSM models, many researchers and industrial practitioners have been able to better understand networks of interactions in complex systems, yielding two primary types of benefits:

- Architecture benefits: planning subsystems or modules, understanding connections across subsystems or modules, identifying the impact of new technology, assessing the match between technical and organizational architectures, designing for modularity, designing for adaptability.
- Integration benefits: planning necessary integration and test activities at component, module, and subsystem levels; identifying problematic interactions that may present integration challenges.

The basic procedure for building as product architecture DSM is as follows:

- Decompose the overall product or system into its subsystems or components. Make the entity-relationship model to identify the all components/parts interaction. Lay out the square DSM with components labeling the rows and columns, grouped into subsystems or modules if appropriate.
- Identify the known interactions between the components and represent these using marks or values in the DSM cells.

The most common method of analysis applied to product architecture DSM models is called clustering. This is a form of partitioning analysis that reorders the rows and columns of the DSM to group the components according to some objective, which usually pertains to the number and strength of the interactions. Clusters or modules may be formed to group components that may achieve efficiencies through common supplier, sharing multiple interfaces, or having complex interactions may be candidates for a cluster/module.

Figure 4.8 shows the flow of a DSM process. The E-R model consisting of 7 entities and 12 relationships is depicted in Figure 4.8(a). The relationships were set using weights. In this case, the two kinds of weight relationships are represented by the number 2 and 10. It should be noted that a stronger relationship is represented by a higher number. Once the weights were assigned, the weighted relationships were represented by a matrix (Figure 4.8(b)). The entities were represented by the vertical and horizontal matrix list, and the relationships were represented by the shell between the horizontal and vertical of the matrix list. The number weight was inserted to the appropriate shell. A clustering algorithm was used to create modules by re-ordering the entity list to obtain a filled shell near the diagonal. In Figure 4.8(c), the clusters (modules) are shown in the black box. The larger number is collected inside the module and the smaller number is placed outside the cluster. The clustering results define the modules, as shown in Figure 4.8(d).

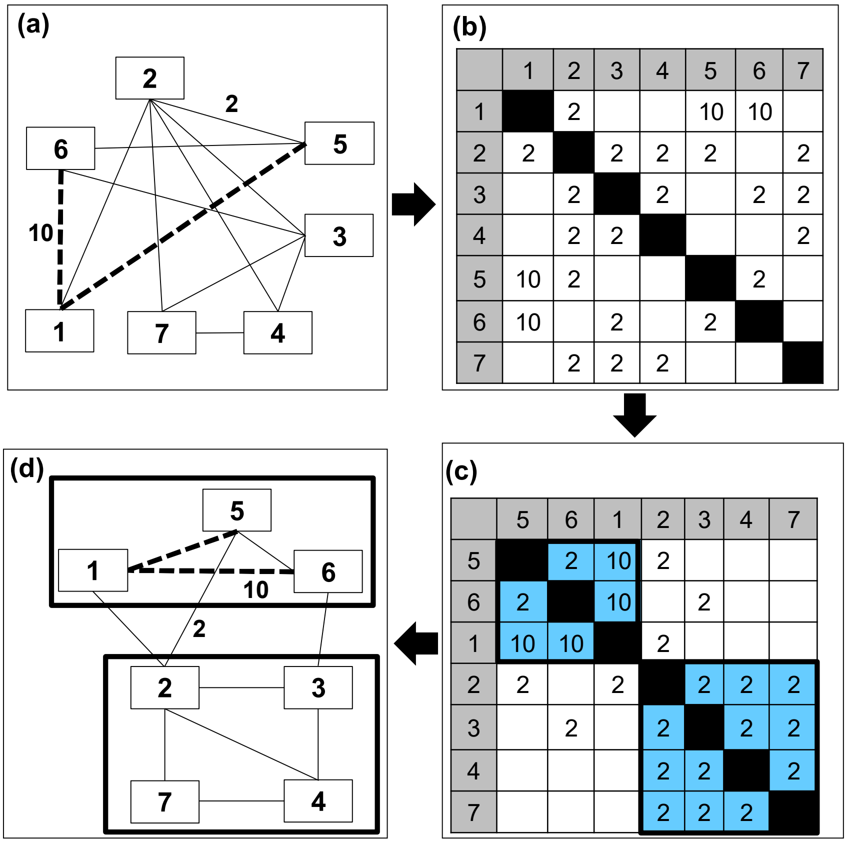


Fig. 4.8 Flow of DSM

(2) Clustering DSM

As discussed above, in order to obtain module from original matrix list, the clustering analysis is adopted. In this chapter, the detail of clustering process is explained. In this study, the weighted DSM as the result from the integration E-R model of each piping system will be modularized using the clustering algorithm. However, in this study, the whole clustering analysis is divided in to two steps; reordering process and clustering process. Furthermore, the detail of reordering process and clustering process are explained in this chapter.

1. Reordering process

As discussed above, in order to obtain module from original matrix list, the clustering analysis is adopted. In this chapter, the detail of clustering process is explained. In this study, the weighted DSM as the result from the integration E-R model of each piping system will be modularized using the clustering algorithm. However, in this study, the whole clustering analysis is divided in to two steps; reordering process and clustering process. Furthermore, the detail of reordering process and clustering process are explained in this chapter.

Reordering is the changing of the DSM rows and columns such that the new DSM arrangement consists of some fill cells move as close as to the diagonal. A rule-based algorithm is used to reorder the DSM rows and columns. The flowchart of reordering algorithm is depicted in the Figure 4.9

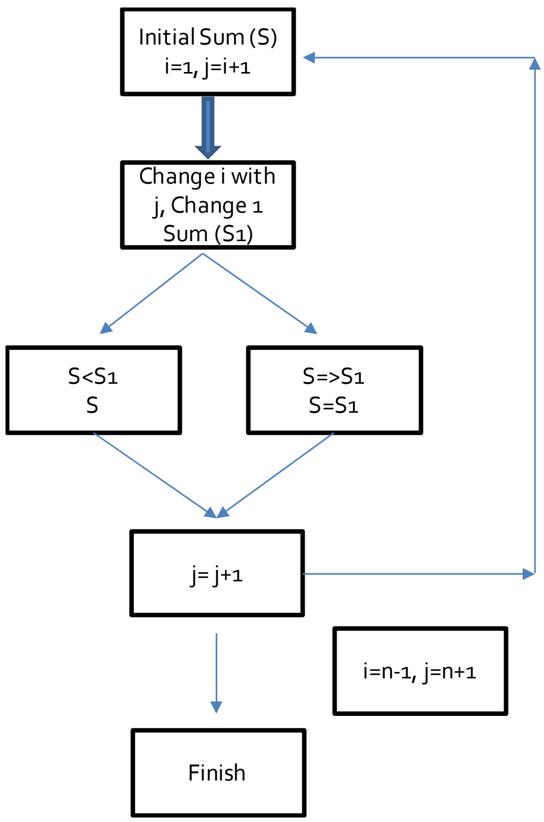


Fig. 4.9 Flow chart of reordering algorithm

Using above algorithm, the optimized DSM arrangement is obtained using the objective function. Smallest sum method (S) is used to obtain the optimized DSM arrangement. The sum of matrix configuration is counted using the smallest sum method. The illustration of smallest sum method is described in the Figure 4.10

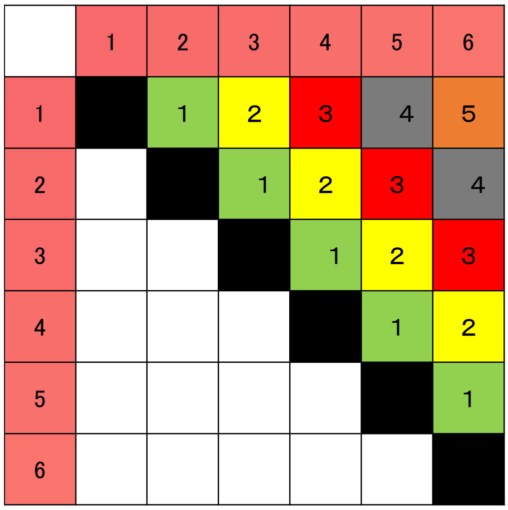


Fig. 4.10 Illustration of smallest sum method

Figure 4.10 shows the rule of the weight factor of the cell in the DSM. First, the diagonal is set as 0 because the diagonal means the self-connection for each entity. Then, the second list upper and lower the diagonal (green color) is set as weight factor number 1. Furthermore, the third, fourth fifth and soon, is noted by weight factor number 2,3,4 respectively. When, the green cell is fill by connection data with certain number, so the sum of the matrix value is certain number multiplied by number 1. The illustration of the Sum of matrix configuration is depicted in the Figure 4.11.

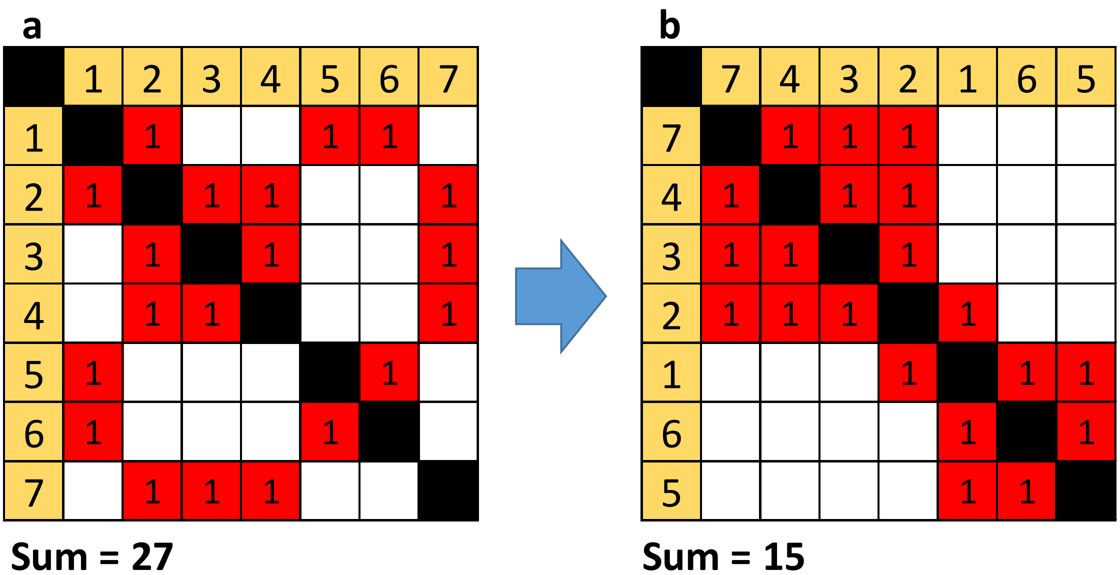


Fig. 4.11 Sum calculation of original DSM and reordering DSM

Figure 4.11 shows the original DSM (a) and reordering DSM (b). In the original DSM, the Sum of the DSM is 27. The detail of the calculation is (4x1) + (1x2) + (1x3) + (2x4) + (2x5) = 4+2+3+8+10 = 27. In this case, the Sum is only calculate the half of DSM because the DSM in this study is symmetry. Therefore, the Sum of half is enough to calculate the Sum of the DSM. In the Figure 4.11 (a), the initial DSM is listed from 1 up to 7 in the matrix entity list both horizontal and vertical. Subsequent, using the reordering algorithm, the optimized result is depicted in the Figure 4.11 (b). The order of matrix change in to 7,4,3,2,1,6,5. Then, the Sum of the reordered DSM is (6x1) + (3x2) + (1x3) = 6+6+3 = 15. Based on the above example, we can conclude that the reordered DSM is better than initial DSM because the Sum value is 15, lower than initial DSM (27). In the other hand, the connection data majorly is move close to the diagonal. Then, the next process is clustering to obtain the optimized cluster (module) configuration.

2. Clustering process

After the initial DSM reordered using rule based algorithm, then the next step is decide the optimum module. Clusters may be formed to group components that my achieve efficiencies through common membership in the cluster. For example, several components produced by a common supplier, sharing multiple interfaces, or having complex interactions may be candidates for a cluster.

Clustering is essentially a type of assignment problem seeking the optimum allocation of the N components to M clusters. Clustering algorithms have many applications besides the DSM, and a variety of algorithms is available. However, a DSM clustering analysis presents several potential challenges. Clustering objective functions for DSM analysis trade off two conflicting goals: (1) minimize the (number and/or strength of) interactions outside clusters, and (2) minimize the size of the clusters. The objective function to be minimized considers both the size of the clusters (C) and the number of interactions outside the cluster (L), according to the following equation, where α is the matrix size (sum of rows or columns) and β is the sum of nodes/shell:

$$Obj = a \sum_{i=0}^{M} C_i^2 + \beta L \qquad (4.1)$$

Clustering analysis also requires attention to the following considerations:

1. Number of clusters. What should be the bounds on M? Without any bounds, an objective function might find it optimal just to call the whole DSM a single cluster (M=1) or to call each components a separate cluster (M=N), although neither of these extreme solutions is typically desirable.
2. Cluster size. A related consideration is if and how to bound the size of each cluster. Usually, a lower bound of a cluster consisting of a single component should be allowed. However, it may be necessary to constraint the maximum number of components that can be assigned to a cluster. Allowing size of clusters to increase essentially limits the maximum number of clusters.
3. Interaction types. The interaction type is the most important point to decide the clustering analysis. There are some examples of interactions: material flow, pipe connection, energy transfer, etc.

In this study, the number of cluster can be varied based on the requirement from the user. The number of cluster effect to the cluster size. Then, the interaction type in this study is pipe connection so the matrix is categorized as the symmetrical matrix DSM. Furthermore, the flow of the clustering analysis is depicted in the Figure 4.12. At first, the user input the number of cluster. Then, program make the combination of matrix based on the 2-divided optimum combination. After evaluate using the objective function, the best configuration is selected.

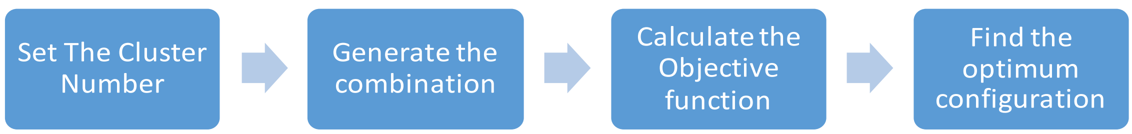


Fig. 4.12 Flow of the clustering analysis

The example of the result of clustering in seawater system is depicted in the figure 4.13 and 4.14

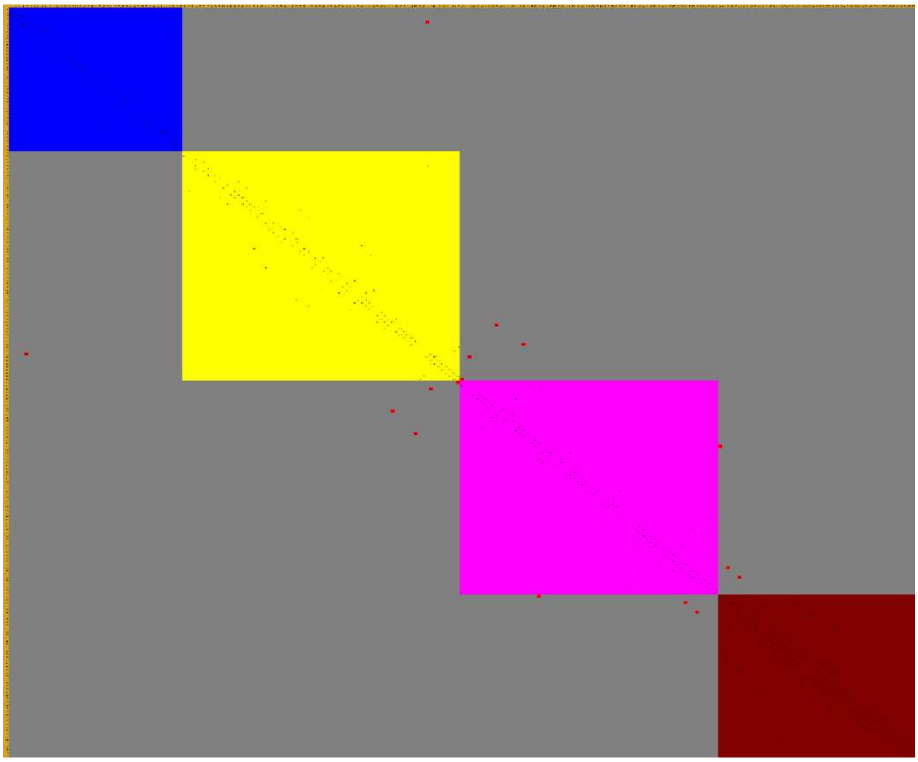


Fig. 4.13 Result of 4 clusters

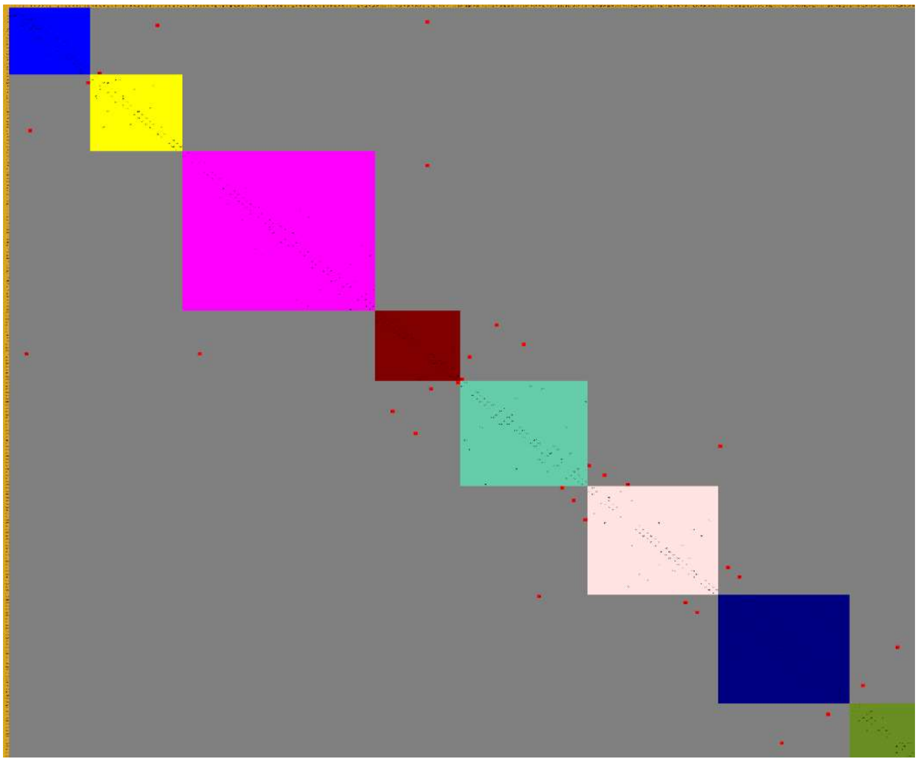


Fig. 4.14 Result of 8 clusters

(4) DSM in this study

In this study, clustering is performed using the weighted DSM. First, the matrices for common parts and optional parts are generated separately. Subsequently, the weights of the connections are set by the following rules:

- Connections for the common parts: The weight is assumed as the cost of the unit length of the corresponding pipe. When two or more pipes exist between the target parts, weight is assumed as the sum of the cost of corresponding pipes.
- Connections for optional parts: First, the weight is calculated in a similar manner to the common connections. Subsequently, the installation probability of the connections is multiplied with the weights.

Once the weights are set, separate clusters of common parts and optional parts are prepared, thereby generating clusters (modules). The flow of the DSM procedure in this study is shown in Figure 4.15.

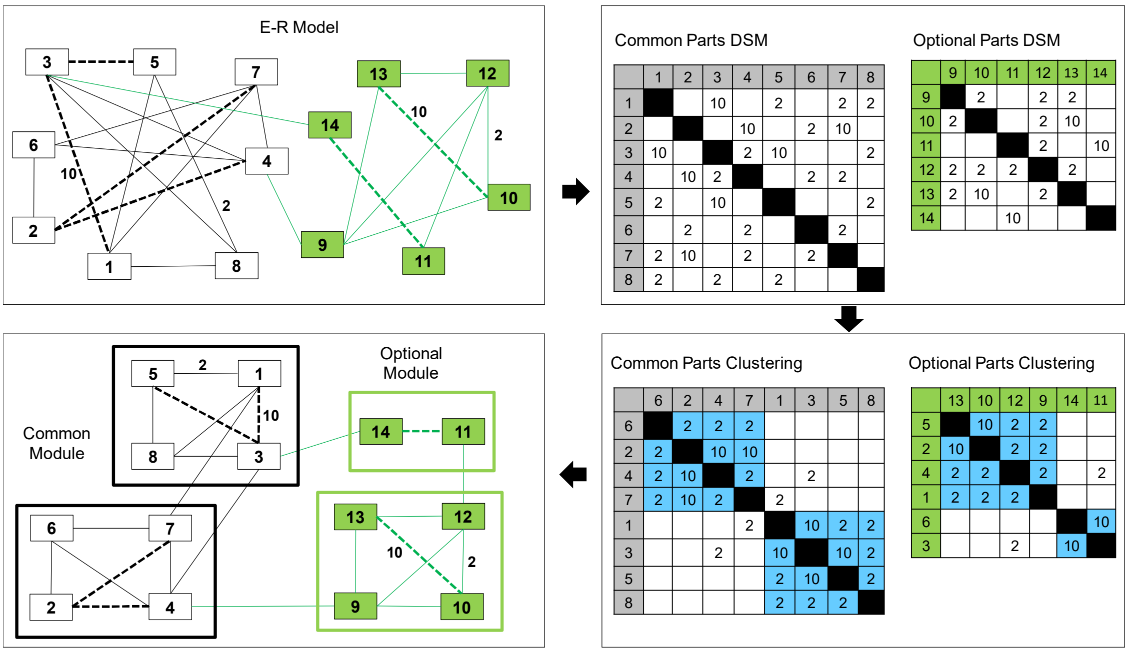


Fig. 4.15 Modularization in this study

4.2.6 Modularization Using DSM

(1) Modularization in seawater system

This section explained the modularization process of seawater system using the method in section 4.1.4.2. First, the entity-relationship model is composed both for common parts and for optional parts. Figure 4.16 shows the entity-relationship model of seawater system.

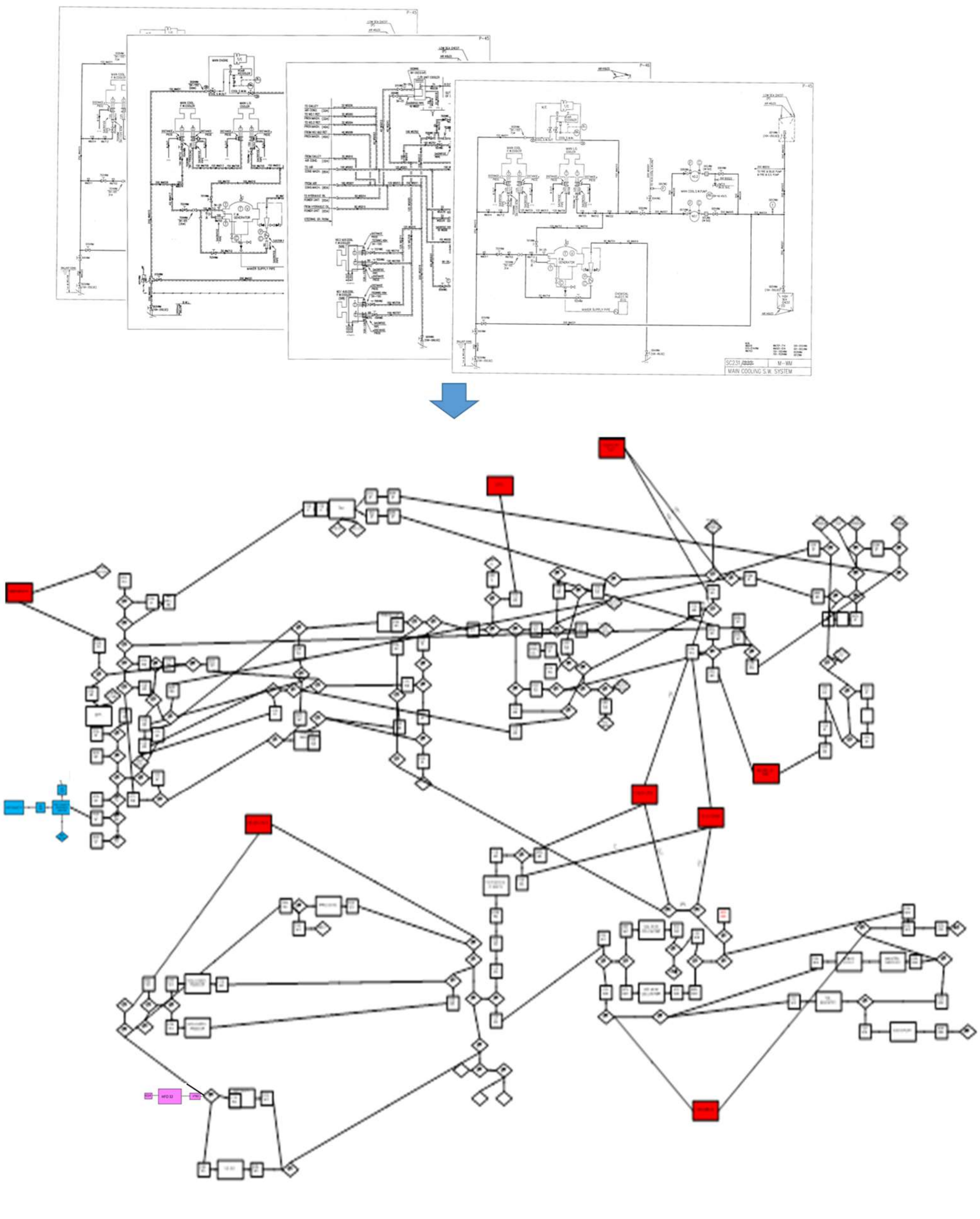


Fig. 4.16 Entity-related model of common part and all option parts

Subsequently, we put only the common entities from Fig.4.16, and create a matrix representation (Fig. 4.17)

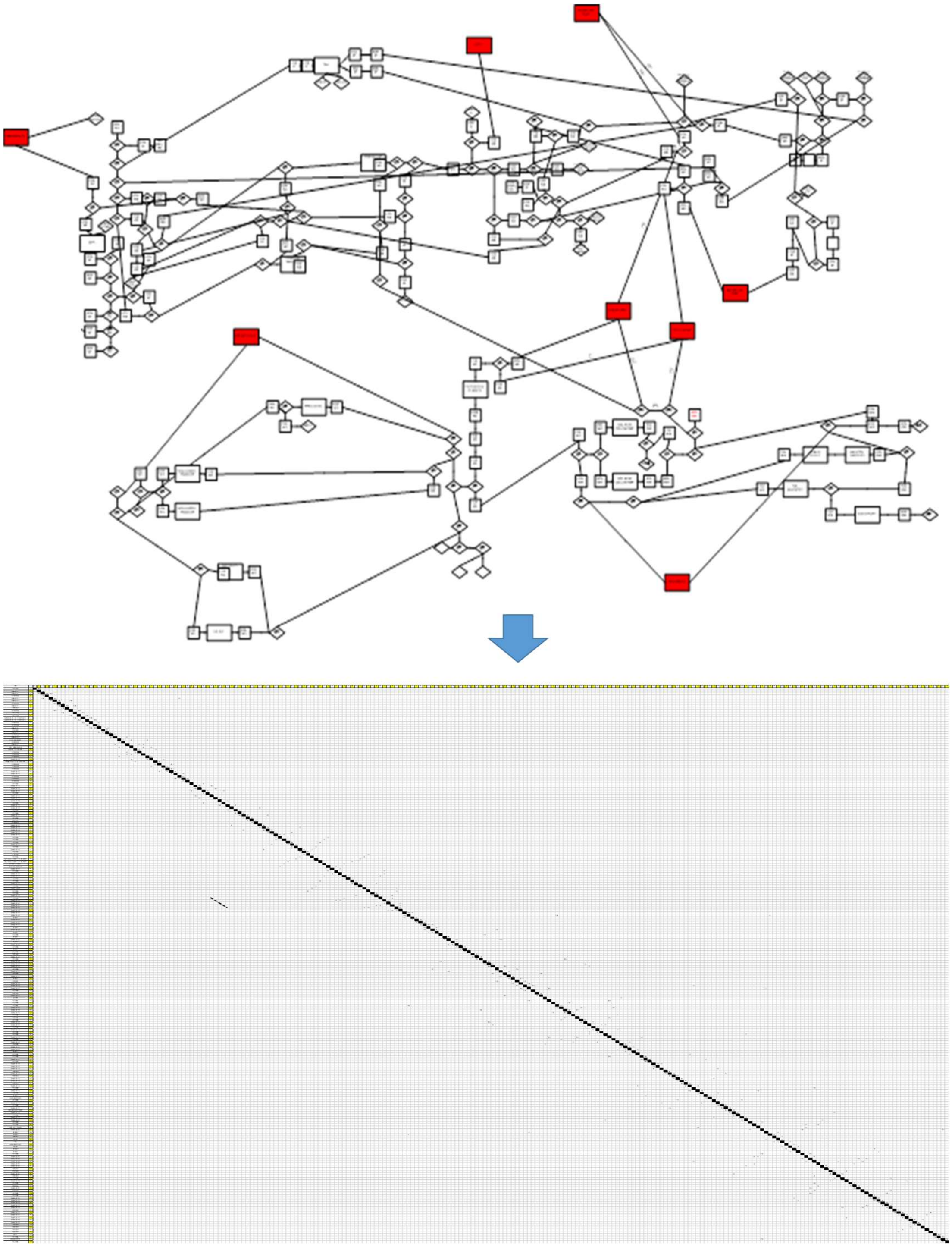


Fig. 4.17 Matrix representation of common entities

In order to create modules, clustering is performed by suing clustering algorithm for common components (Fig. 4.18)

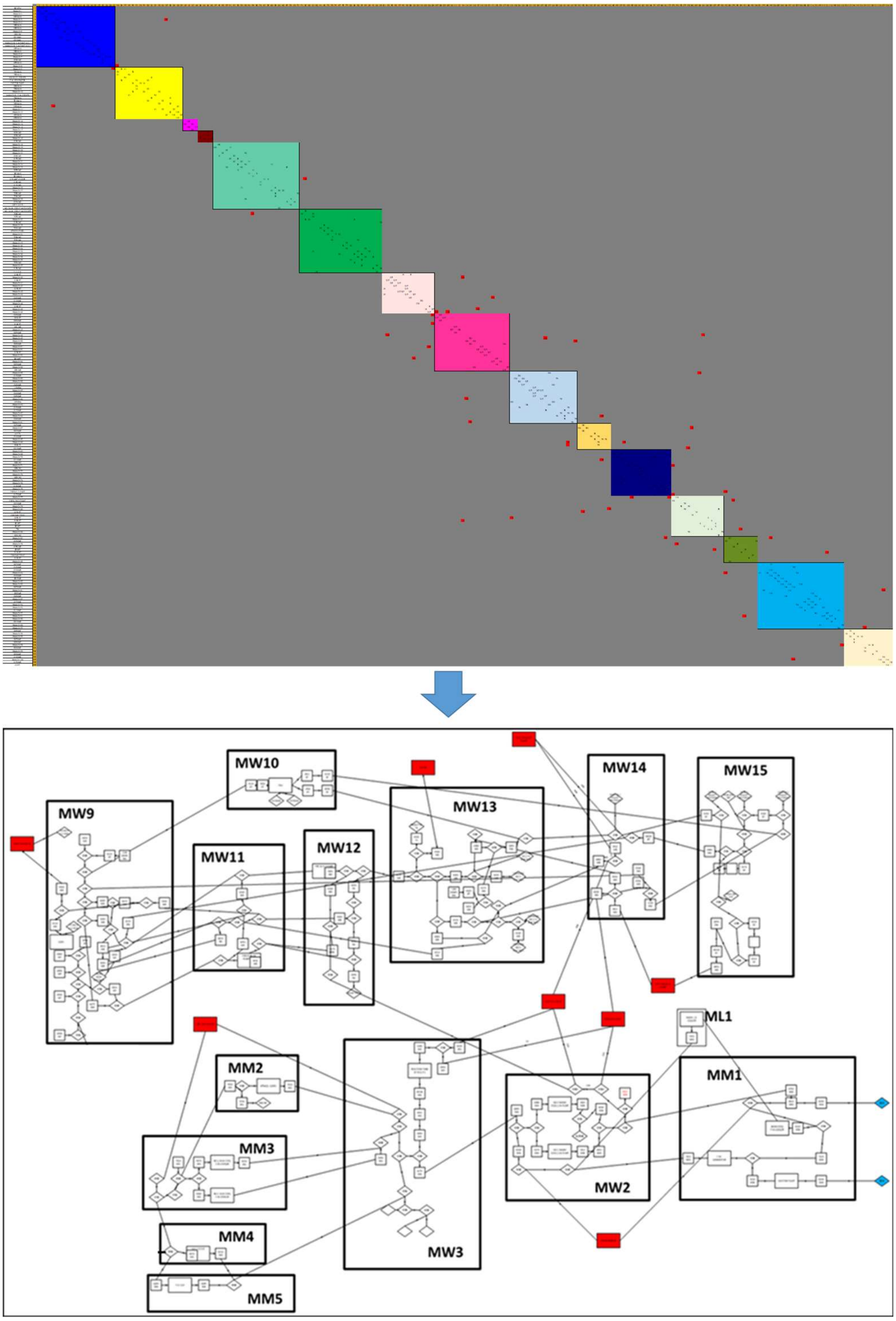


Fig. 4.18 Modularization of common entities

Next step is input the optional entities into the common modules data (Fig. 4.18) and compose new matrix representation (Fig. 4.19)

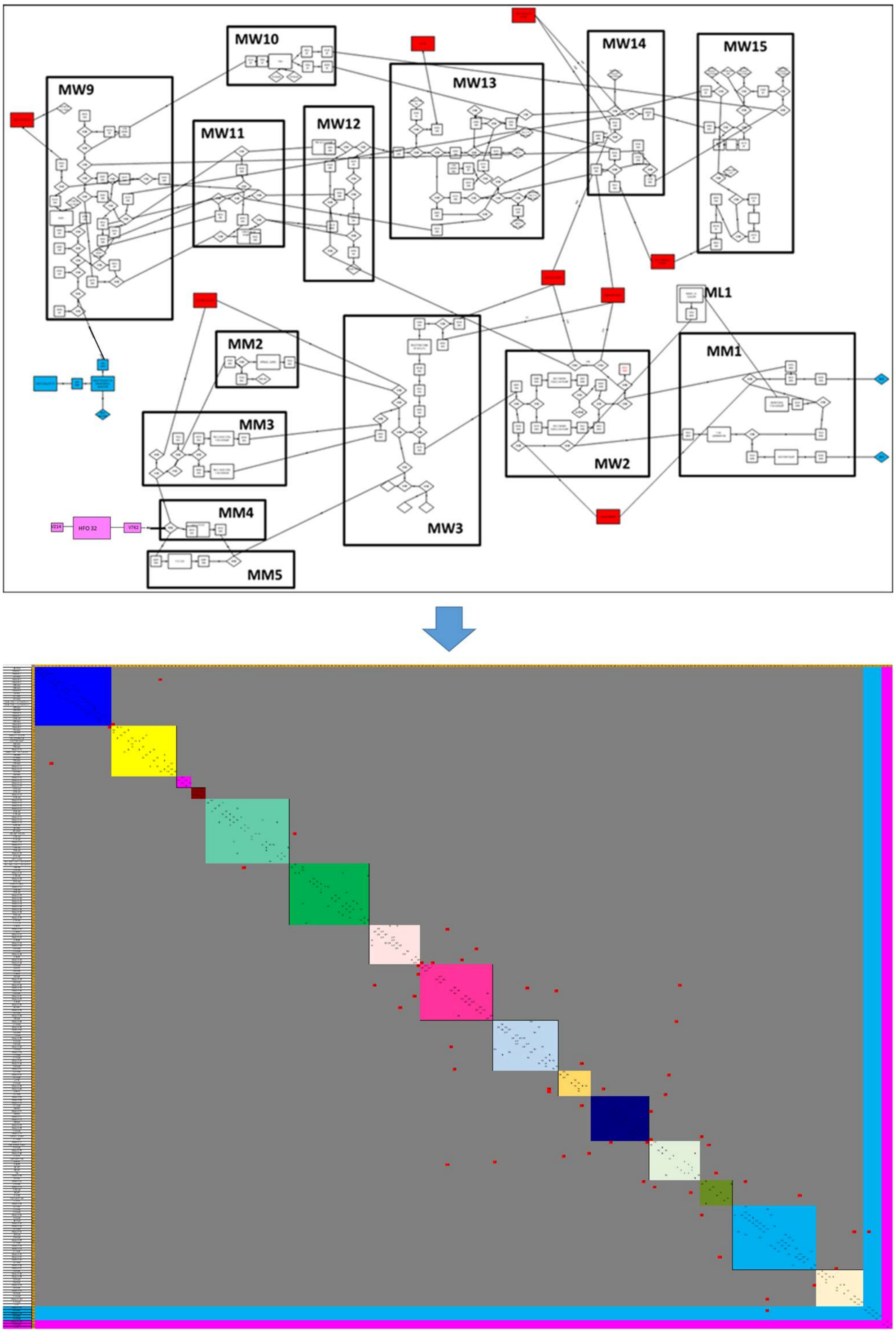


Fig. 4.19 New matrix representation including optional entities

Subsequently, clustering for optional entities is performed. Figure 4.19 shows the modularization result both common entities and optional entities.

4.3 Modularization Result

4.3.1 Modularization in seawater system

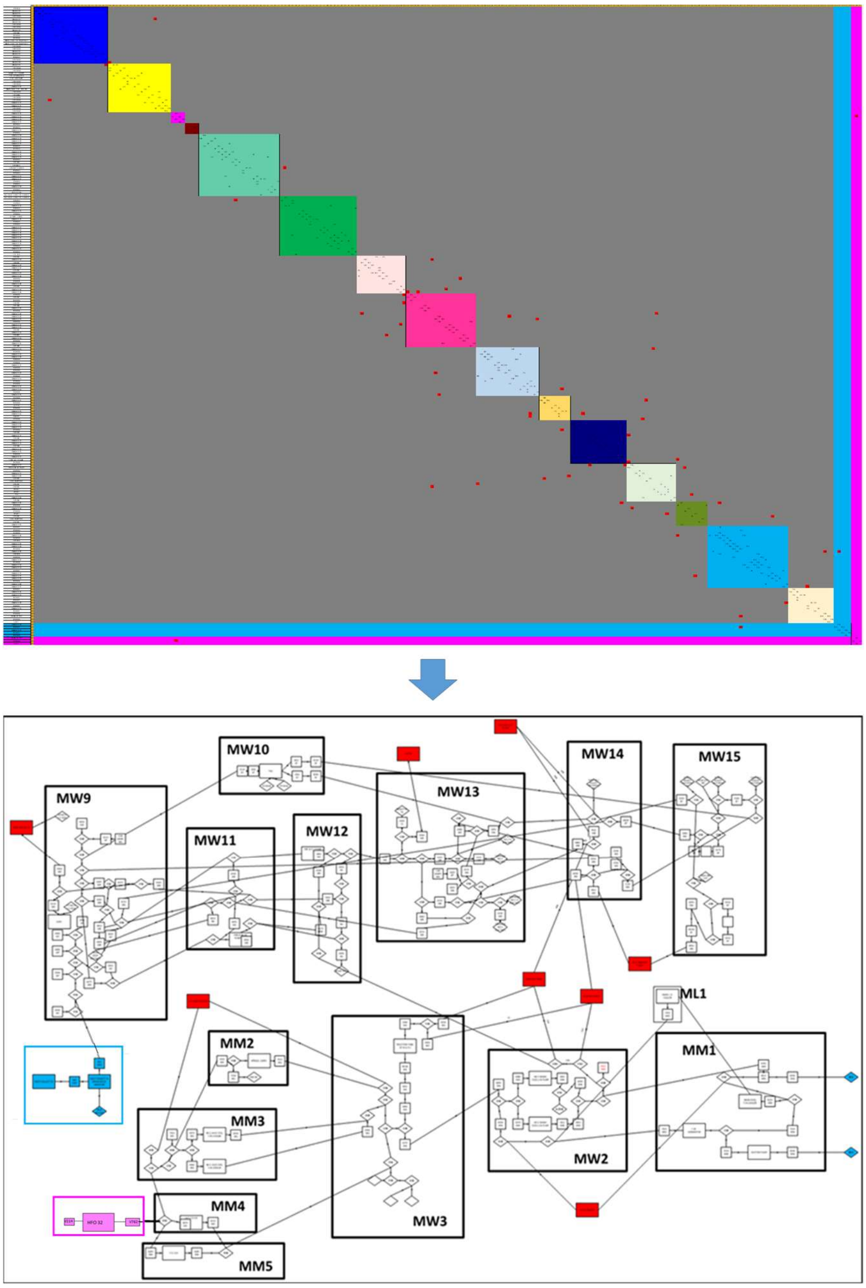


Fig. 4.20 Modularization result of seawater system

4.3.2 Modularization in freshwater system

By using same way, the modularization result in fresh water system as described in the Figure 4.21

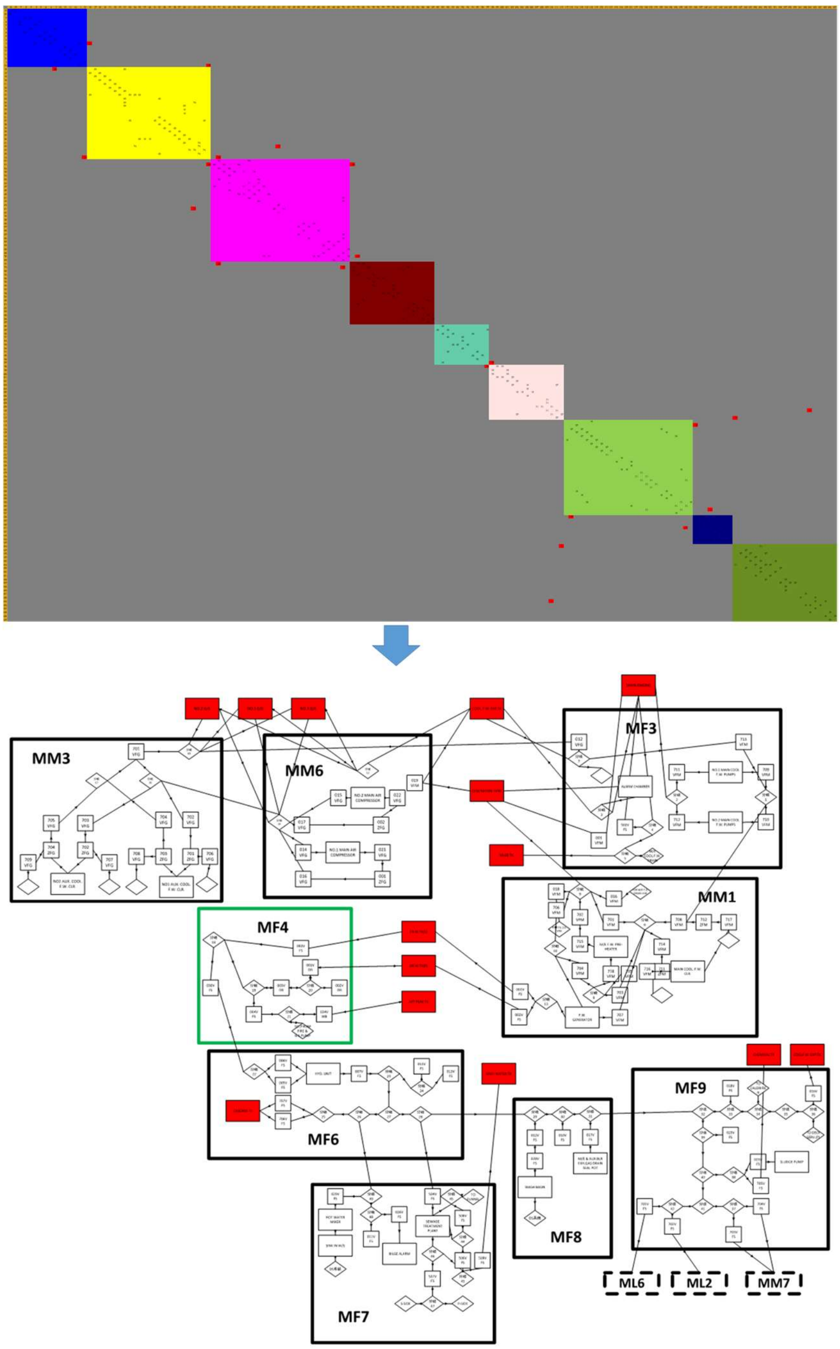


Fig. 4.21 Modularization result of fresh water system

4.3.3 Modularization in fuel oil system

By using same way, the modularization result in fuel oil system as described in the Figure 4.22

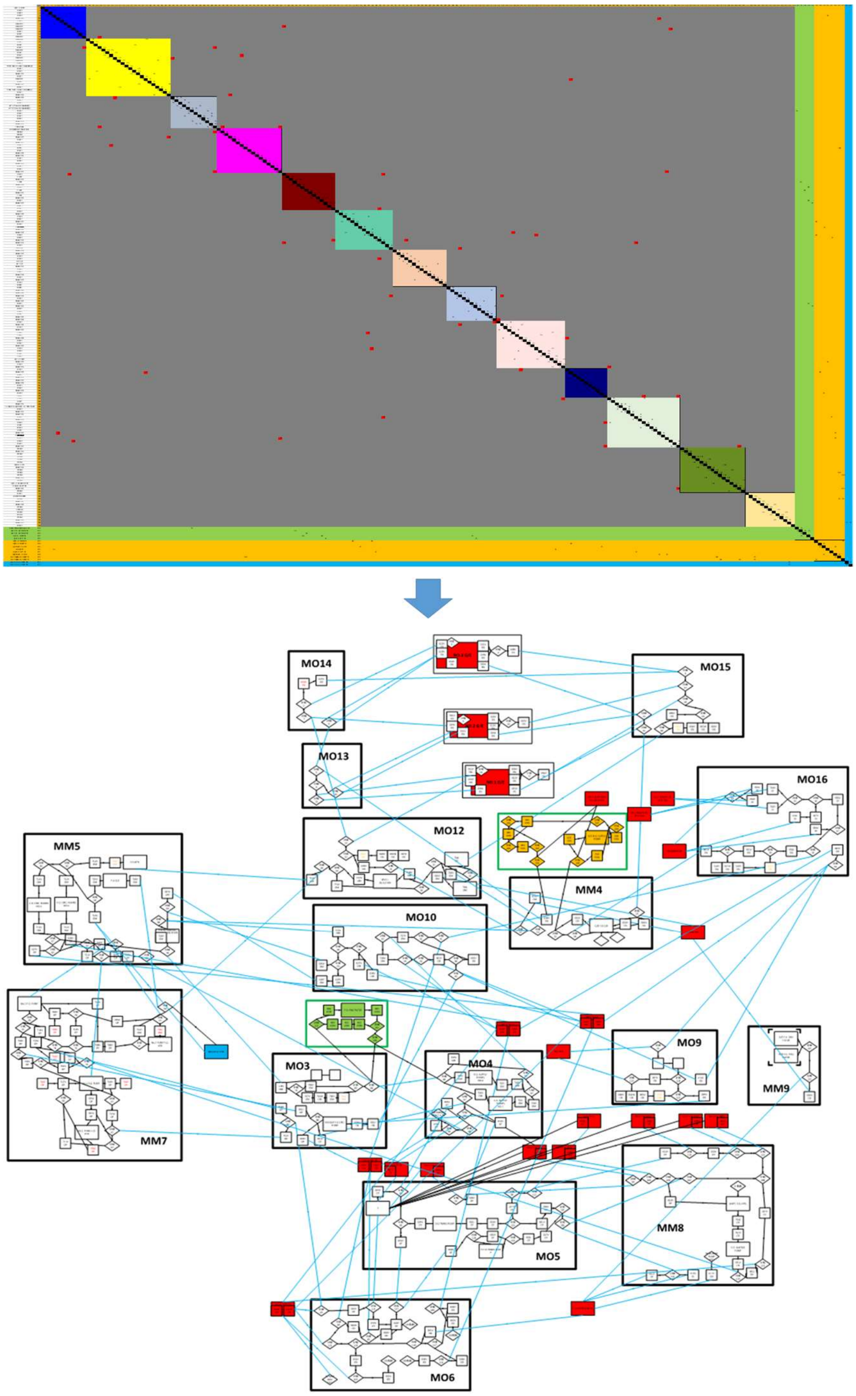


Fig. 4.22 Modularization result of fuel oil system

4.3.4 Modularization in lube oil system

By using same way, the modularization result in lube oil system as described in the Figure 4.23

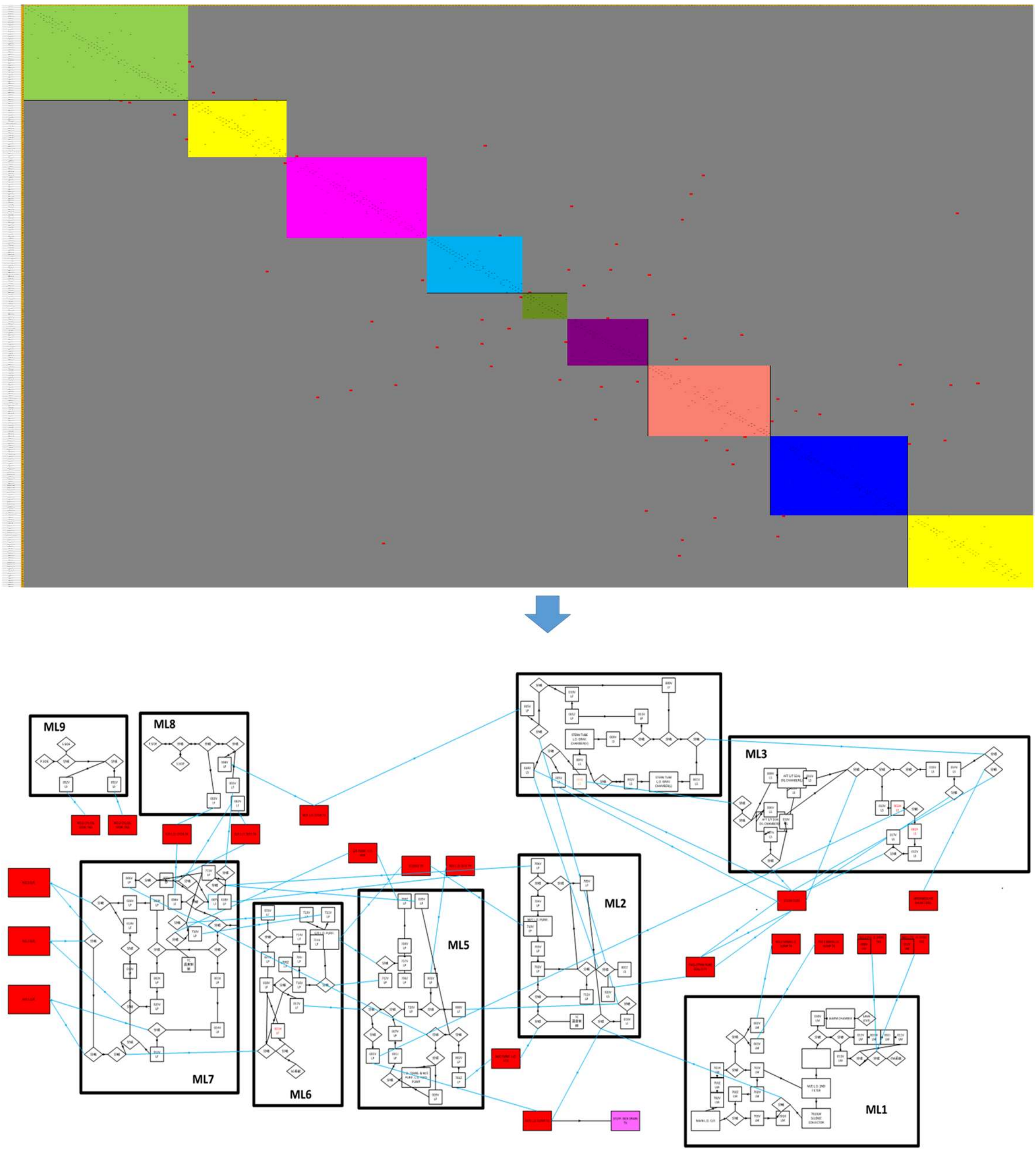


Fig. 4.23 Modularization result of lube oil system

4.3.5 Modularization in steam system

By using same way, the modularization result in steam system as described in the Figure 4.24

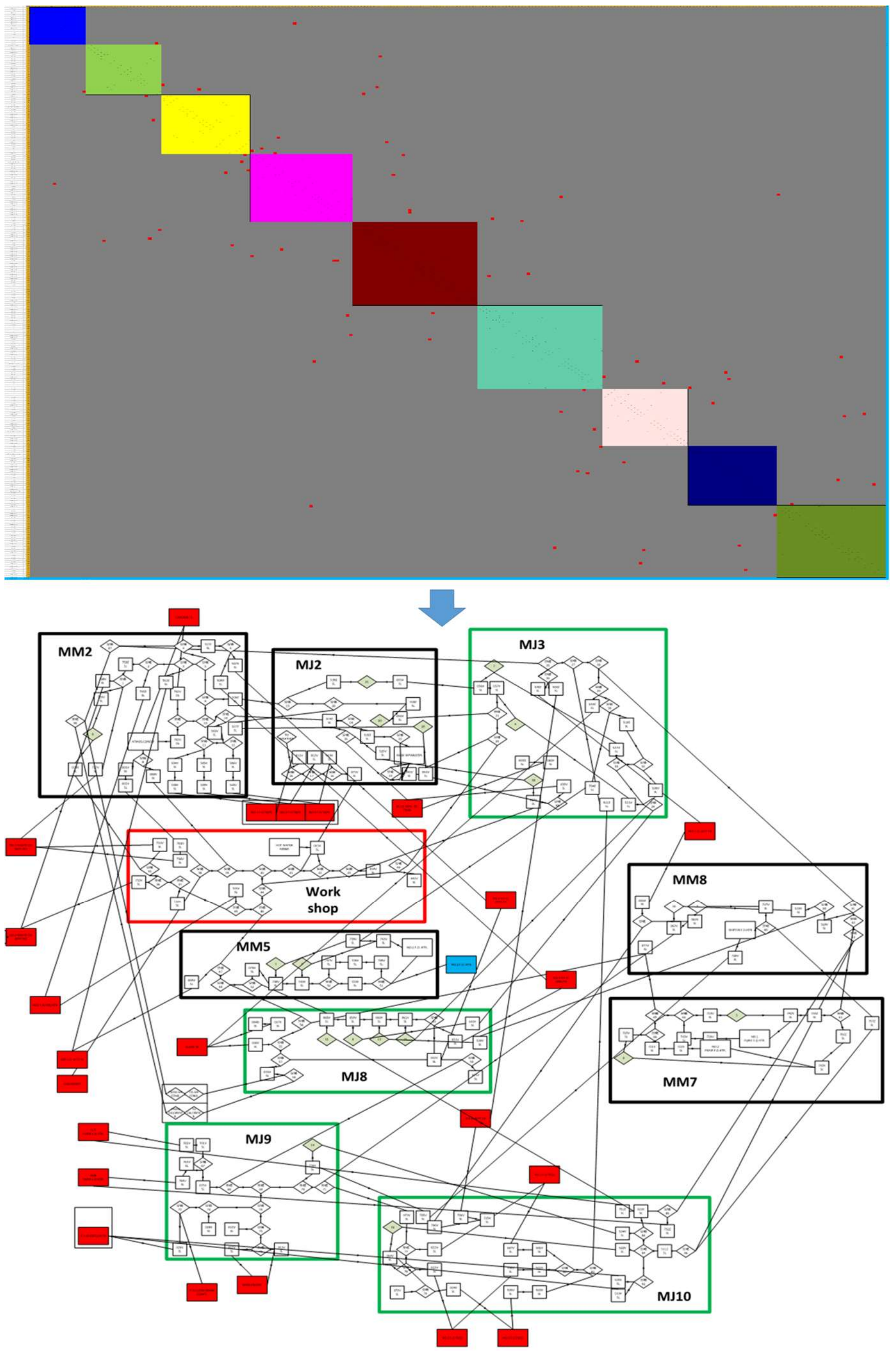


Fig. 4.24 Modularization result of steam system

4.3.6 Modularization in compressed air system

By using same way, the modularization result in compressed air system as described in the Figure 4.25

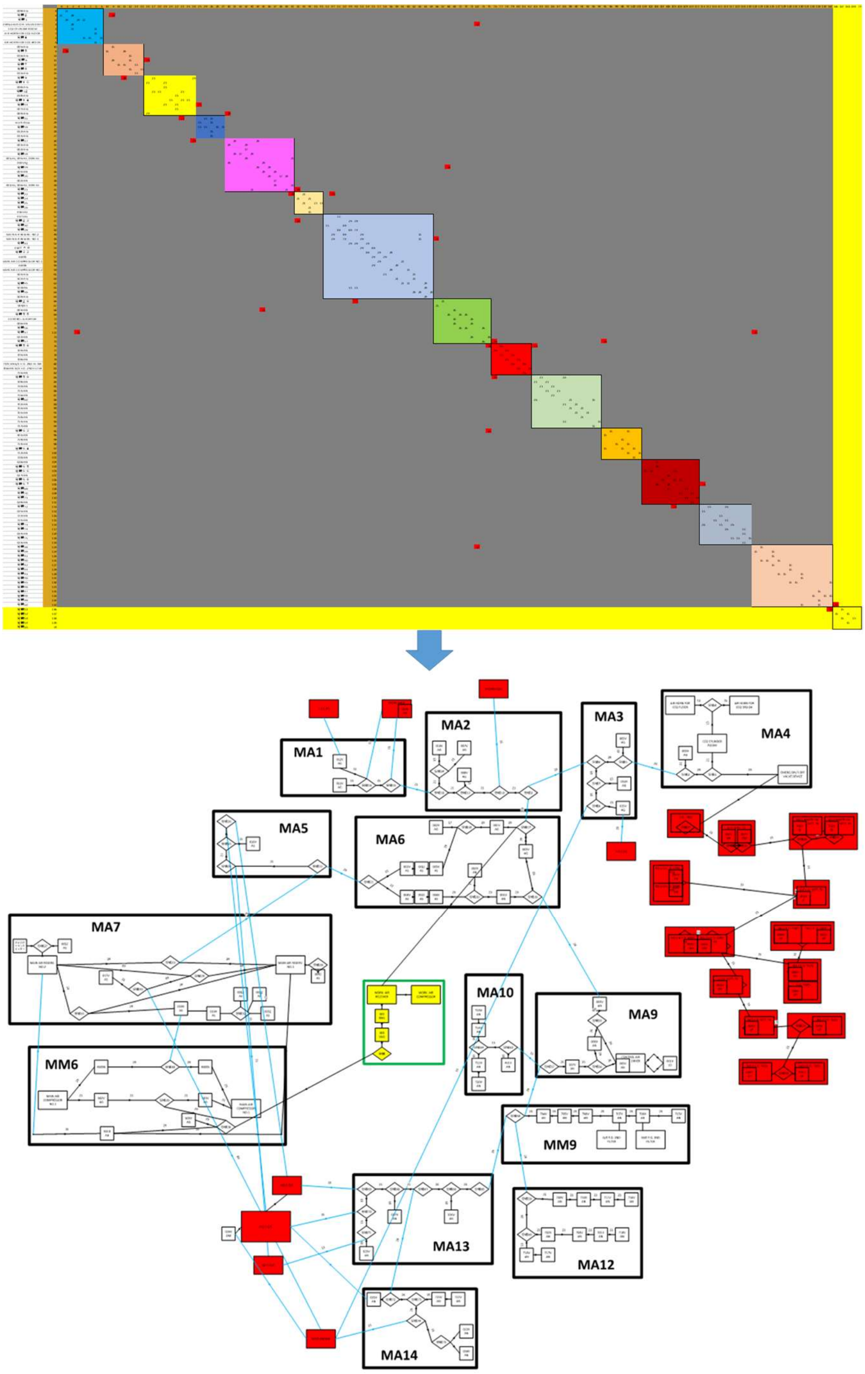


Fig. 4.25 Modularization result of compressed air system

4.4 Evaluation of the Modularization Result

The result of modularization for all piping systems is described in the previous chapter. Each piping system modularized using the DSM procedural concept. Fig. 4.20 - 4.25 show the modularization result for six piping systems. In order to evaluate the effectiveness of the proposed method, the modularization result of seawater system is discussed below.

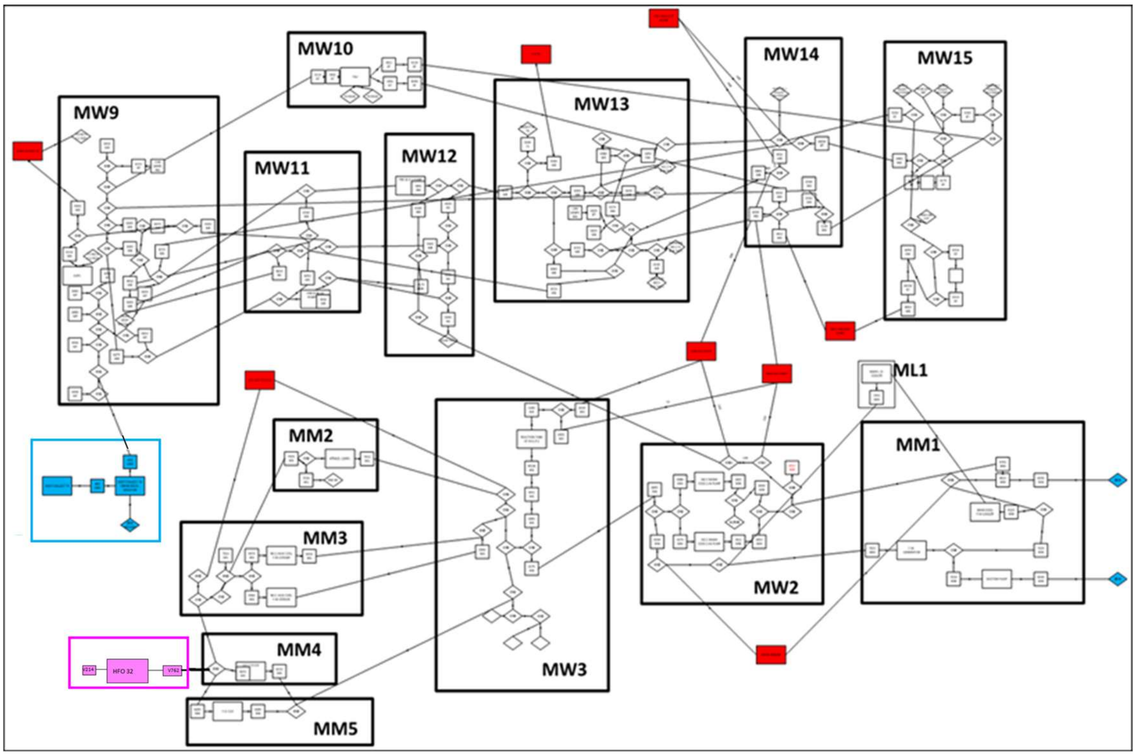


Fig. 4.26 Modularization result of seawater system

Consider the example of a seawater system; it comprises 233 common and 8 optional components. This type of modularization is realized for a single ship or a series of ships, and also for ships belonging to various series types that could be established with 15 common and 2 optional modules. Each module can be varied in capacity or size with no change to its configuration. Therefore, it was possible to configure a new piping system combining all modules. The arrangement comprises 40 pipe connections between the grouped modules and 233 pipe connections within the modules.

According to the modularization requirements as denoted in the chapter 3.2.2, the modularization result should be evaluated using the following requirements.

- **Module should be defined for a single ship, a series ships, and for various types of series ships**

The result of modularization in seawater piping system as denoted in the Figure 4.26, modules as the result from all ships in all series. In this case, 15 common modules and 2 optional modules are generated. This result means that in the seawater piping system, each individual ship in all series consists of 15 common modules. All ships have same number of the common modules. The differences is located in the module size and capacity of each series, according to the differences of the owner requirements. In a word, the commonness modularization concept is implemented in this dissertation. The size and capacity differences of the module are not considered as the important point, because it not affected in the module configuration.

However, the optional module is adopted in several ships. In this case, the optional module is shoot collect tank and fine filter. In the adoption rate data, shoot collect tank module is adopted in the 25% of the total ships. It can be said that if the total ships were built in all series are 100 ships; therefore, 25 ships are equipped with this optional module (shoot collect tank module). Furthermore, the configuration and number of common modules in all series are the same. However, the configuration and number of optional modules may be different. Table 4.1 shows the illustration of module configuration in each ship in case same series and different series.

Table 4.1 Module configuration in each ship in same series and different series

		Seawater piping system	
		Common modules	Optional modules
58BC	Ship A	15 modules	1 module
	Ship B	15 modules	no module
	Ship C	15 modules	2 module
	Ship D	15 modules	no module

82BC	Ship A	15 modules	1 module
	Ship B	15 modules	no module
	Ship C	15 modules	2 module
	Ship D	15 modules	no module
98BC	Ship A	15 modules	1 module
	Ship B	15 modules	no module
	Ship C	15 modules	2 module
	Ship D	15 modules	no module

- **Modularization for common parts should be separate from that of the optional parts**

In the series ship concept, the differences of part specification inside engine room is possible due to the differences of the owner requirements. However, in this concept, the differences only for several part as the additional requirement from the certain owner. Therefore, only in the particular ships are equipped with some optional part. In order to create the commonness modularization, common part and optional part should be separately. Common part for each system is modularized for all ships at the same time. In a word, the modularization of common part, come from the integration part lists of certain system in all series ships. As the result, the commonness of common module is obtained.

Subsequent, the optional part is modularized according to the additional part data from certain ship that equipped with additional part. Therefore, the optional part is not included in the common module. Optional part is modularized into some optional module. Figure 4.26 shows the modularization result in the seawater piping system. According to this result, the common part and optional part are modularized separately. In addition, two optional module are generated from the 8 optional parts.

- **Based on the owner's requirements, both common and optional modules should be able to change in capacity and size without a change in the module configuration.**

The commonness modularization concept allow for the change of the part capacity and size without change in the module configuration. Since, the module design is obtained, that is possible for owner to require some changes related to the part properties inside the module. Figure 4.27 shows the illustration of module change in term of capacity and size.

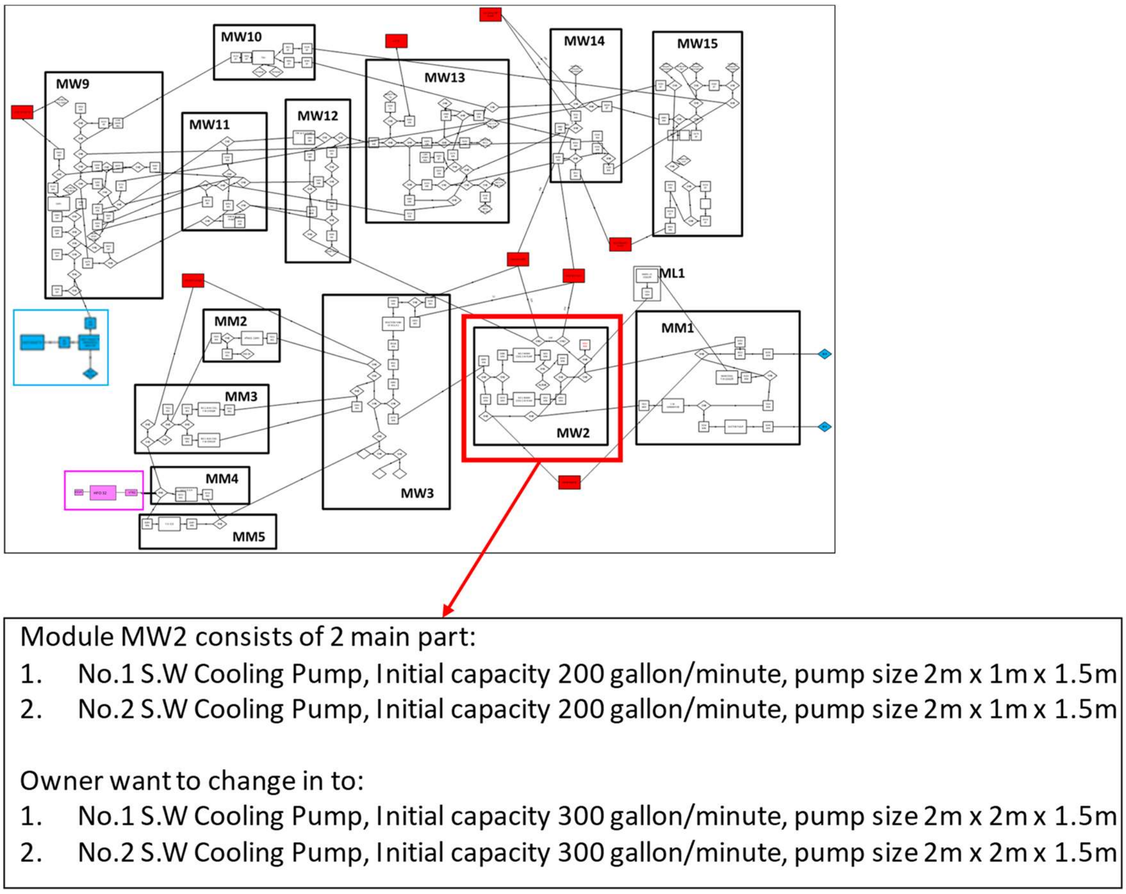


Fig. 4.27 Change of then module capacity and module size

Figure 4.27 shows, in case the owner requires change of the part capacity that effect of the module size, however, the configuration of module is not changed. For the example, module MW2 consists of two main parts; no. 1 S.W cooling Pump and no. 2 S.W cooling Pump. These pumps capacity are changed based on the owner requirement, therefore the size of new pump is twice. Consequently, the size of module MW2 increased two times. However, the module configuration is not changed.

- **A combination of common modules and optional modules should be possible to obtain a new ship type based on the owner's requirements.**

One of the some advantages of the proposed modularization concept in this dissertation is to simplify the owner to require new ship type (piping system). Combine the common module and optional module obtain the new piping system type. In case of Figure 4.26, there are 15 common modules and 2 optional modules in the seawater piping system. In case of the owner requires new type of seawater piping system, they just make a combination of these modules. For the example, the new type is consists of only 13 common modules excluding module MM4 and MM5. Furthermore, only shot collect tank module is installed as the optional module. Based on above requirement, the modularization of seawater piping system is depicted in the Figure 4.28.

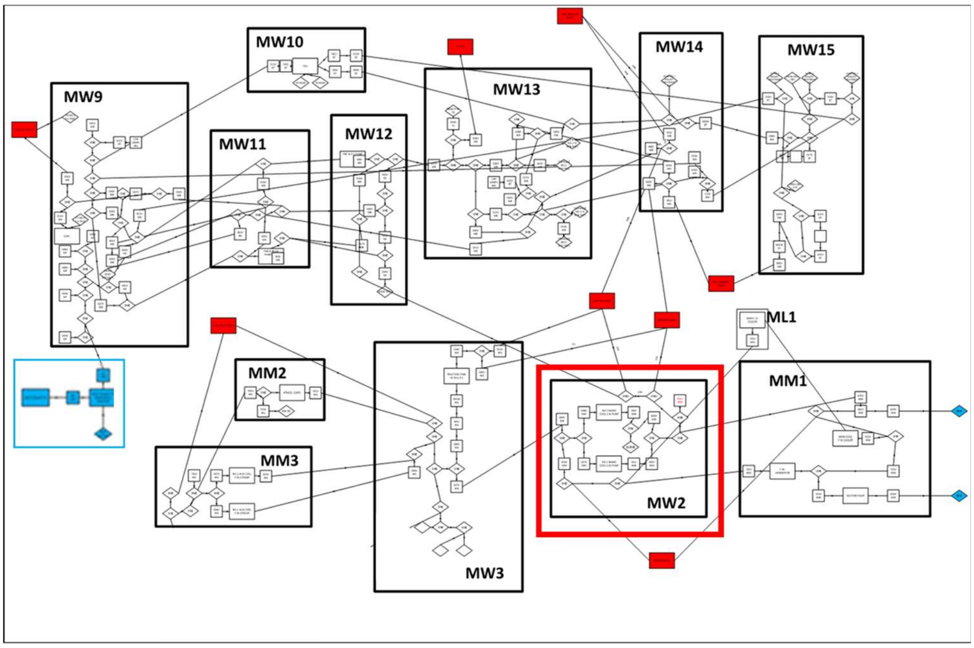


Fig. 4.28 New combination of common module and optional module to obtain new piping system type

- **To use the modularization concept effectively, complex connections should be included in the module. Therefore, connections between the modules should be minimized.**

This requirement is one of the best way to measure the effectiveness of the module. As described in the chapter 1 and chapter 2, that the modularization is adopted in order to compete the complex system of the piping design inside engine room. The piping system is a complex system including huge piping connection of among parts. Modularization should be able to simplify this complexity. According to the result of modularization in this dissertation, we would like to shows the example of modularization result. In order to shows the complex connection of the module, Figure 4.29 shows the highlight of part module result in freshwater piping system.

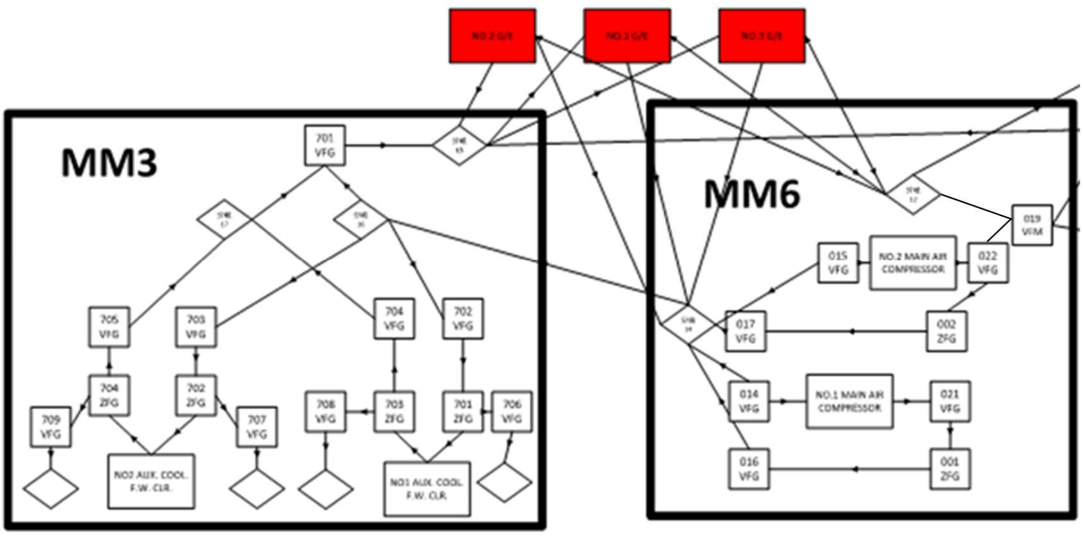


Fig. 4.29 Part of module in freshwater piping system

Figure 4.29 shows the connection between module MM3 and module MM6. The straight line means the pipe connection. Based on this Figure, there is only one pipe connection between MM3 and MM6. However, inside of module MM3, there are 23 pipe connections. In case of inside module MM6, there are 14 pipe connections. Based on above description, this requirement is fulfilled using the proposed modularization concept.

4.5 Conclusions of Modularization

Conclusions of this chapter are as given below.

(1) A new method of modularization of ship piping system inside engine room is proposed.

(2) The modularization is addressed inconsideration of various series ships.

(3) In order to obtain the commonness of modularization, common part and optional part are modularized separately.

(4) Common part modularization is modularization for all common parts in each piping system for all series ships in the one time. Therefore, the integration common part list is defined before the modularization.

(5) Optional part modularization is modularization for all optional parts in each piping system for all series ships that equipped with additional part based on the owner requirement. This modularization is proceed in one time. Therefore, the integration of optional part list is defined before the modularization.

(6) Design structure matrix (DSM) is adopted in order to modularize the part in each piping system. Therefore, E-R model is created before the DSM process.

(7) The result of modularization is fulfilled with the all requirements of modularization.

(8) Finally, effectiveness of modularization is evaluated.

Chapter 5

Arrangement Optimization

5.1 Overview of Arrangement

5.1.1 Arrangement of single ship

In the module arrangement problem, the similarity position for all series ships is the most important consideration. Therefore, in this research, module consists of two types: common module and optional module. In the previous study, the optimized arrangement is obtained for each ship. The arrangement is executed one by one for each ship in case of several ships will be arranged. The arrangement of one ship, the optimized arrangement is the local optimization. In other words, since the target ship is changed, therefore the arrangement design is proceed from the initial process. Consequently, the design time and design cost are increased gradually. Figure 5.1 shows the optimized module arrangement in one ship.

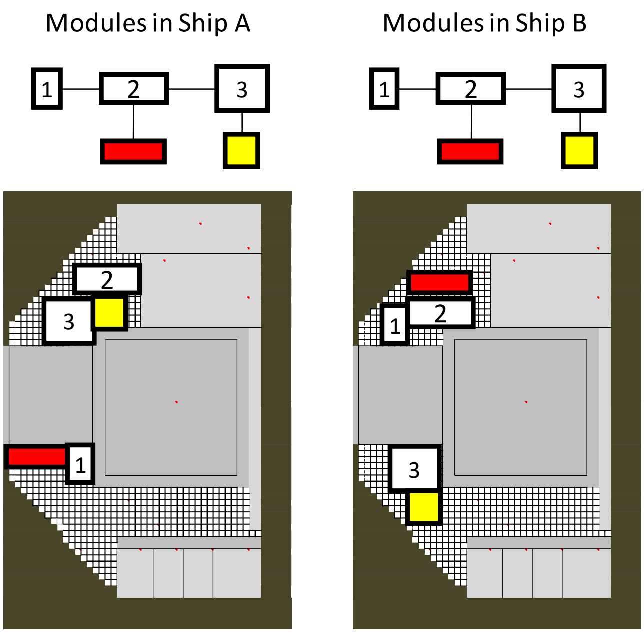


Fig. 5.1 Optimized arrangement for each ship

Figure 5.1 shows the optimized arrangement for each ship. Even though, the module configuration of ship A and ship B is same, therefore, the arrangement is different. The optimized arrangement is different because in this case, the optimization is executed one by one. Therefore, the similarity concept in not considered in this case. In addition, the target of optimization in one ship is minimized the pipe cost.

5.1.2 Arrangement of one series ships

Subsequent, the next previous studies of optimization in one series is addressed. In this case, the similarity is considered for each series optimization besides the minimized pipe cost. The result of this optimization is similarity arrangement in one series. However, in case of different series, the arrangement is different. The illustration of optimization in one series is depicted in the Figure 5.2.

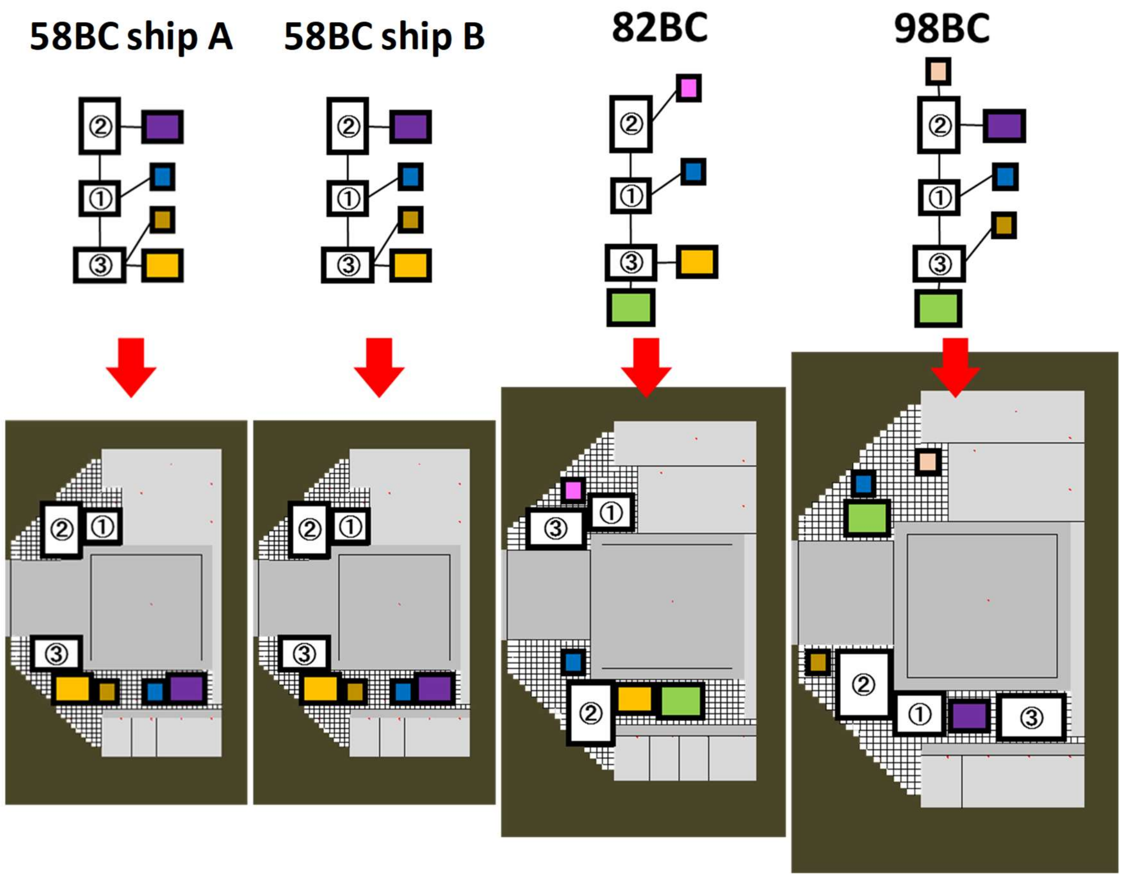


Fig. 5.2 Optimized arrangement for each series

Figure 5.2 shows the optimization arrangement of each series. In this case, the arrangement of all ships in one series is same. However, the arrangement of different series is different.

The target ship of this dissertation is various series ships with different size. Therefore, the standard arrangement design is considered in order to obtain the design efficiency. The detail of the procedure to obtain similarity arrangement inconsideration of carious series ships is depicted in the next chapter.

5.2 Basic Concept of Optimization

In the arrangement design, modules defined in the previous section are arranged in the engine room. To realize the arrangement for series ships of different sizes, the following concepts were introduced in this study;

- Concurrent arrangements of three series ships were executed. Hence, various options could be considered at once.
- In the aforementioned case, the design space becomes relatively large; moreover, it is difficult to obtain an optimum solution within a limited time when the positions of modules are directly treated as design valuables. Therefore, decks in the engine room and the modules were divided into meshes.
- The cost of the pipes and similarity of arrangements were set as objective functions.
- A genetic algorithm was adopted for optimization.

Above concepts are the characteristics of the proposed arrangement method in this dissertation. The description of the above characteristics is explained in the followings:

5.2.1 Concurrent arrangements of three series ships

In order to obtain the similarity arrangement, the integration of all E-R model in all series is required. In this case, both for common and optional module are arranged in the same time. The illustration of concurrent arrangement is depicted in the Figure 5.3

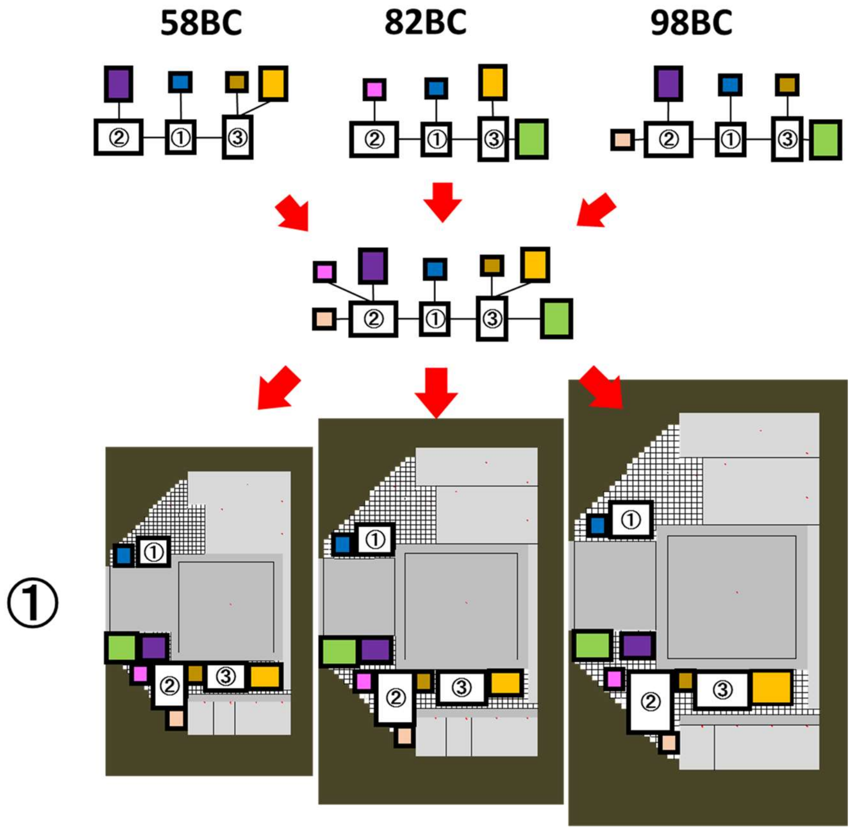


Fig. 5.3 Concurrent arrangement of common module and optional module

The additional procedure should be adopted to obtain the similar arrangement. Therefore, the following procedure is important.

- Compose the integrated module data in all series at the same time. Adoption rate is considered only in optional module. Furthermore, integrated module data will be arranged by optimization method. Cost and similarity are adopted as the objective function.

- In accordance with the specification of optional module of each ship, unnecessary optional modules are removed from the arrangement.

First, as shown in Fig. 5.3, common module and optional module are arranged in all series simultaneously. At that time, taking into consideration the adoption rate of how many of each optional module is adopted. The adoption rate for the common module is 100%. The next process is remove the unnecessary optional module based on the initial module data. Figure 5.4 shows the result of the optimized arrangement. By using the above procedure, it is possible to reduce the design step and cost because of the similarity module arrangement. The detailed arrangement optimization will be explained in the next chapter.

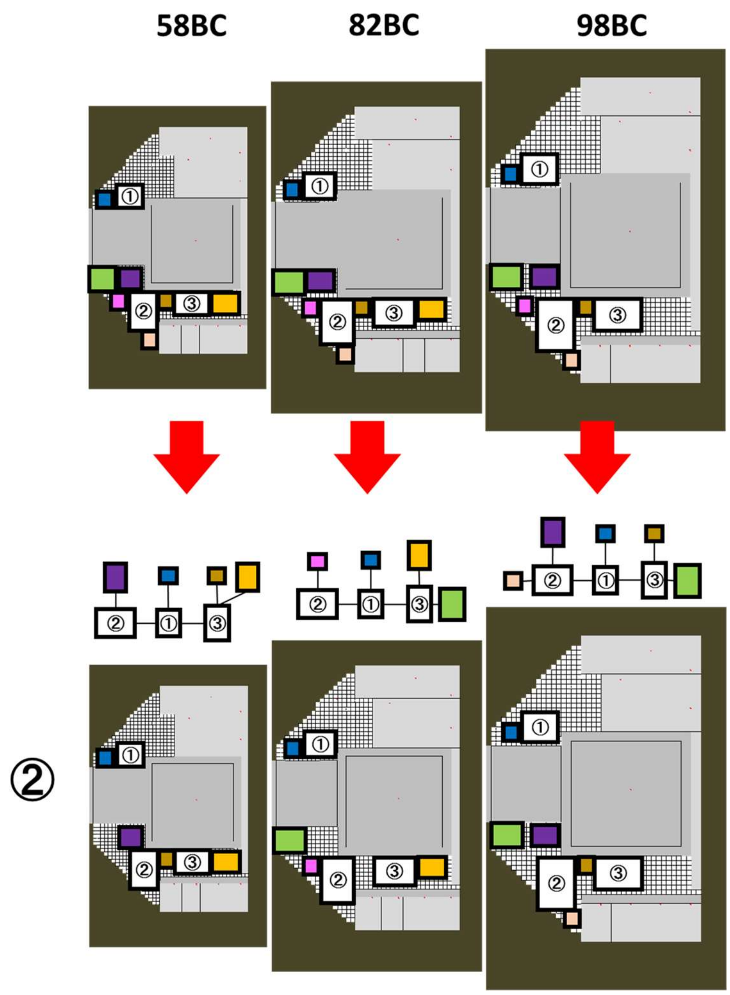


Fig. 5.4 Result of optimized arrangement in various series ships

5.2.2 Meshes of deck and module

Due to the large of the design space of optimization, the optimum solution might be difficult to obtain in the real size condition. In order compete this problem, the meshes process of deck and module inside engine room are required.

5.2.3 Objective function

The optimized arrangement should be comprises of two aspects; minimized of the pipe cost and obtain the standard design (similarity arrangement). These two aspect are very important to get the total optimization solution inconsideration of various series ships. The pipe cost is related to the total pipe length were produced in the arrangement. The detail of the objective function is explained in the next chapter.

5.2.4 Optimization using genetic algorithm

Generally, there are some optimization technique can be selected in order to solve the optimization problem. Some techniques such as: genetic algorithm, simulated annealing, ant colony, particle swarm optimization and etc. However, in this dissertation, genetic algorithm is selected to solve the problem. Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by replying on bio-inspired operators. The detail of the genetic algorithm in this dissertation is explained in the chapter 5.4 and 5.5.

The arrangement optimization comprises of the following procedures.

1. Initial condition (user input)
2. Optimization program using genetic algorithm
3. Optimization result and evaluate the effectiveness

The detail of each procedure is explained in the following chapter.

5.3 Initial Condition (User Input)

The deck information, module information, and the pipe information between modules were input by user before optimization. These were treated as the initial condition of the arrangement optimization. Initial condition consists of three input data: deck information, module information and pipe information. The detail of each input data, will be explained in the next chapter.

5.3.1 Deck information

It is necessary to set a deck shape for arrange equipment, tanks, valves etc. inside the engine room. In this research, the deck shape is represented by a set of squares. Deck shape and allowable arrangement space are different in each series. In this study, three series ships were set as targets with each ship having a three-deck structure. Therefore, information on nine decks was input as the initial condition. Consequently, the mesh size was set as 40 cm x 40 cm.

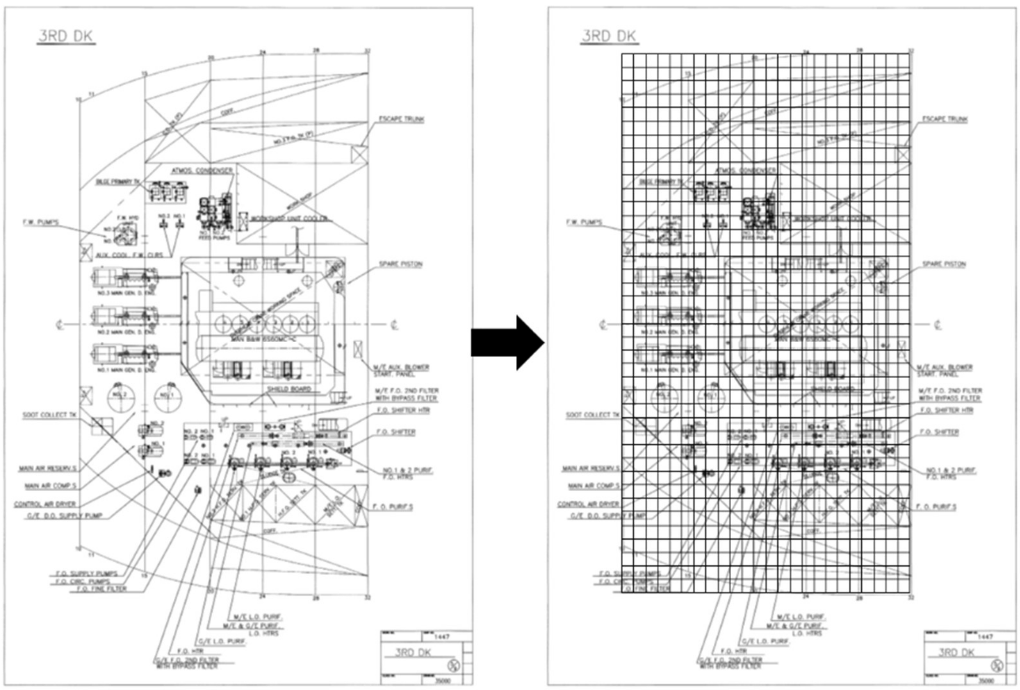


Fig. 5.5 shows mesh division.

The each target ship in this dissertation comprises of three level decks; floor, 3rd deck and 2nd deck. Each deck is meshed using the previous procedure as denoted in the Figure 5.5. Each deck has the different size and different allowable arrangement area.

Subsequent, setting of allowable arrangement area is needed. Figure 5.6 shows the detail of the deck information.

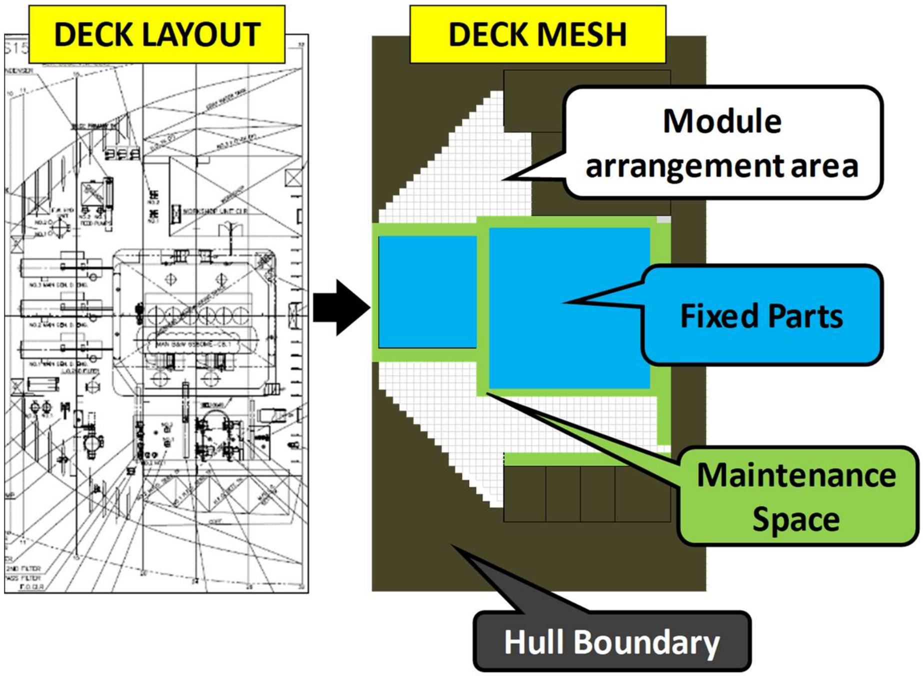


Fig. 5.6 Deck information

Figure 5.6 depicts a simplified example of deck information; the following information was input as deck information.

- The black area represents hull boundary of the ship.
- The blue area represents a few fixed parts, such as the main engine and tank. The arrangement of modules and pipe, however, could not be accomplished.
- The green area is provided as maintenance space. The arrangement of modules is not allowed but for pipe arrangement is allowed.
- In the white area, all modules were arranged.

In this study, three series ships were set as targets with each ship having a three-deck structure. Therefore, information on nine decks was input as the initial condition.

The deck meshes in created in the excel file. In order to identify the differences of the obstacles area and allowable arrangement area, in the excel file, the meshes is inserted with different number. In this case, the hull boundary area is inserted by number 2, the fix part area and maintenance space are inserted by number 1, and finally the allowable arrangement area is inserted by number 0 or just in blank format. In this program, the deck data of each series is merged in one excel file. Therefore, in this study conducted 3 deck data file; 58BC series, 82BCb series and 98BC series respectively. Figure 5.7 shows the deck data of 58BC series on 3rd deck port side

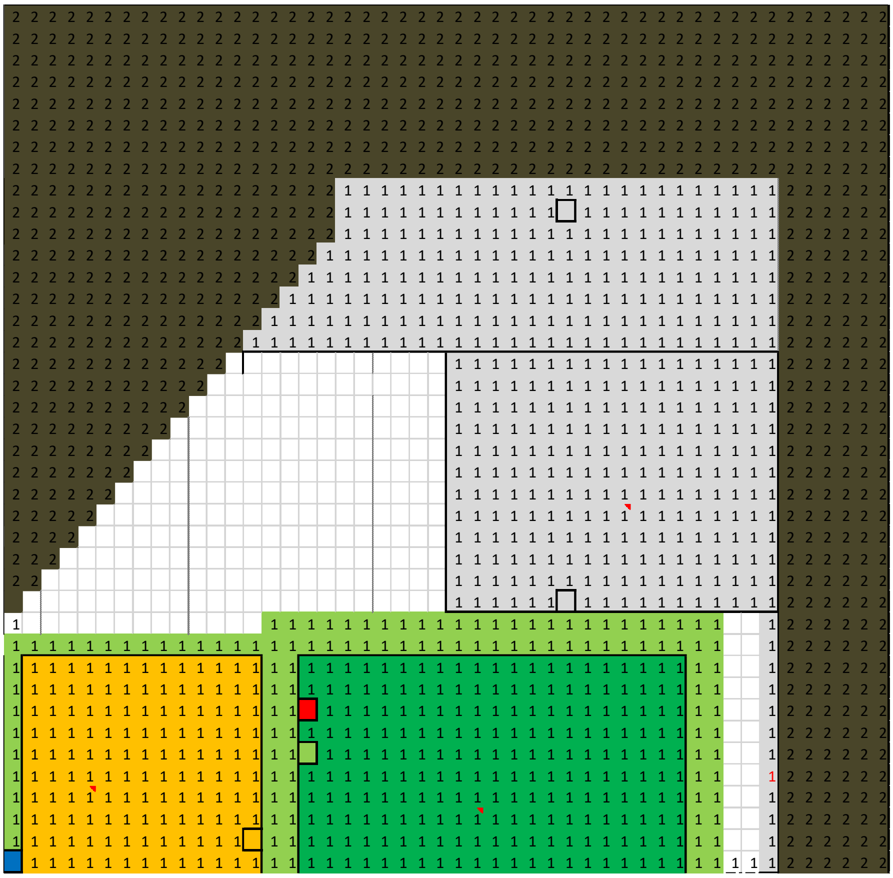


Fig. 5.7 Deck information of 58BC series on 3rd deck port side

5.3.2 Module information

Module information comprises the information concerning on the size and limitations of the arrangement. In order to arrange the modules, it is necessary to determine the size of the module. In this research, the size of the module is decided based on the size of the equipment included in the module defined in the previous chapter, and it is represented by a set of squares. The module sizes are different in each target series.

As seen in Table 5.1, modules A and B possess a size of 6 columns × 4 rows and 5 columns × 5 rows, respectively. Both modules (A and B) were to be arranged on the 3rd deck. Module A was to be arranged on the starboard side and module B on the portside.

Table: 5.1 Module information of 58BC series

ID	C	R	PARTIAL	3rd DECK	2nd DECK	S or P
A	6	4		1		S
B	5	5		1		P

Table: 5.2 Module information of 82BC series

ID	C	R	PARTIAL	3rd DECK	2nd DECK	S or P
A	6	4		1		S
B	5	6		1		P

Table: 5.3 Module information of 98BC series

ID	C	R	PARTIAL	3rd DECK	2nd DECK	S or P
A	8	6		1		S
B	7	7		1	1	P

Module information also provide some fix part information and position. Specifically, fix part position is directly decided in the module information data using the coordinate of column and row. The data of fix part is provided by the company. Therefore, the fix parts are arranged based on the position data inserted in the module excel data.

5.3.3 Pipe information

Pipe information indicates the number of pipe connections between modules along with weight-per-unit-length data for each pipe. The data are used to calculate the pipe length and weight. The pipe connection data is collected from the E-R data. Figure 5.8 shows the illustration of the pipe connection data between modules.

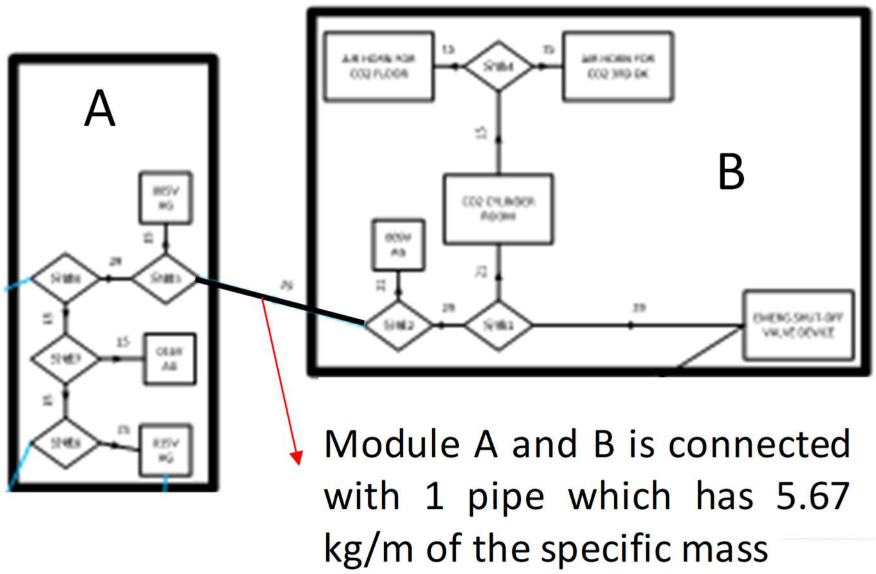


Fig. 5.8 E-R model of 2 modules.

Table 5.4 represent an example of pipe information and pipe weight data. As denoted red color in the table, there exists a single pipe between modules A and B, the weight per unit length (kg/m) for this pipe was determined to be 5.67 kg/m as shown in the table 5.4.

Table: 5.4 Pipe information of 58BC series

ID	A	B	C	ID	A	B	C
A		1		A		5.67	
B	1		1	B	5.67		3.24
C		1		C		3.24	

Subsequent, the optimization program using the genetic algorithm is proceed to obtain the optimized arrangement inconsideration of various series ships. Furthermore, the objective function in this program comprises of two elements; cost minimization and similarity arrangement for all series.

In this dissertation, the genetic algorithm is adopted to arrange the modules. therefore, the brief overview of genetic algorithm is required. The overview of genetic algorithm is explained in the chapter 5.4. Furthermore, the detail of genetic algorithm in this dissertation is depicted in the chapter 5.5.

5.4 Overview of Genetic Algorithm

Genetic Algorithms (GA's) are adaptive heuristic search algorithm premised on the evolutionary ideas of natural selection and genetics. Genetic Algorithms was invented by John Holland in the 1960s with original goal was not designed to solve specific problems, but rather to formally study the phenomenon of adaptation as it occurs in nature and develop ways in which the mechanisms of natural adaptation might be imported into computer systems. The basic concept of genetic Algorithms is designed to simulate processes in natural system necessary for evolution, specifically, the principle of survival of the fittest that laid down by Charles Darwin in his theory of evolution [Gen & Cheng, 1997]. As such a representative an intelligent exploitation of a random search within a defined search space to solve a problem.

Genetic Algorithms are rooted in both natural genetics and computer science. The terminologies used in genetic algorithm literature are a mixture of the natural and the artificial. In a biological organism, the structure that encodes the prescription specifying how the organism is to be constructed is called a chromosome. One or more chromosomes may be required to specify the complete organism. The complete set of chromosomes is called genotype, and the result organism is called phenotype. Each chromosome includes a number of individual structures called gene. Each gene encoded a particular feature of organism, and the location, or locus, of the gene within the chromosome structure determines what particular characteristic the gene represents. At a particular locus, a gene may encode any of several different value of the particular characteristic it represents. The different values of a gene are called alleles. The genetic algorithms term and optimization terms are summarized in Table 5.5.

Table 5.5 Explanation of Genetic Algorithm Terms

Genetic Algorithms	Explanation
Chromosome (string, individual)	Solution (coding)
Gene (bits)	Part of solution
Locus	Position of gene
Alleles	Value of gene
Phenotype	Decoded solution
Genotype	Encoded solution

The general structure of genetic algorithm is shown in Fig. 5.3, starting with an initial set of random solutions called initial population. Each individual in the population is called chromosome, representing a solution to the problem. The chromosomes evolve through successive iteration, called generations. During each generation, the chromosomes are evaluated using some measures of fitness. To create the next generation, new chromosomes, called offspring, are formed by either merging two chromosomes from current generation using a crossover operator or modifying a chromosome using a mutation operator. A new generation is formed by selection, according to the fitness values. Some of the parents and offspring are rejected so as to keep the population size constant. Fitter chromosomes have higher probabilities of being selected.

After several generations, the algorithms converge to the best chromosome, which hopefully represents the optimum or sub optimal solution to the problem. Various GA procedures are explained in the followings.

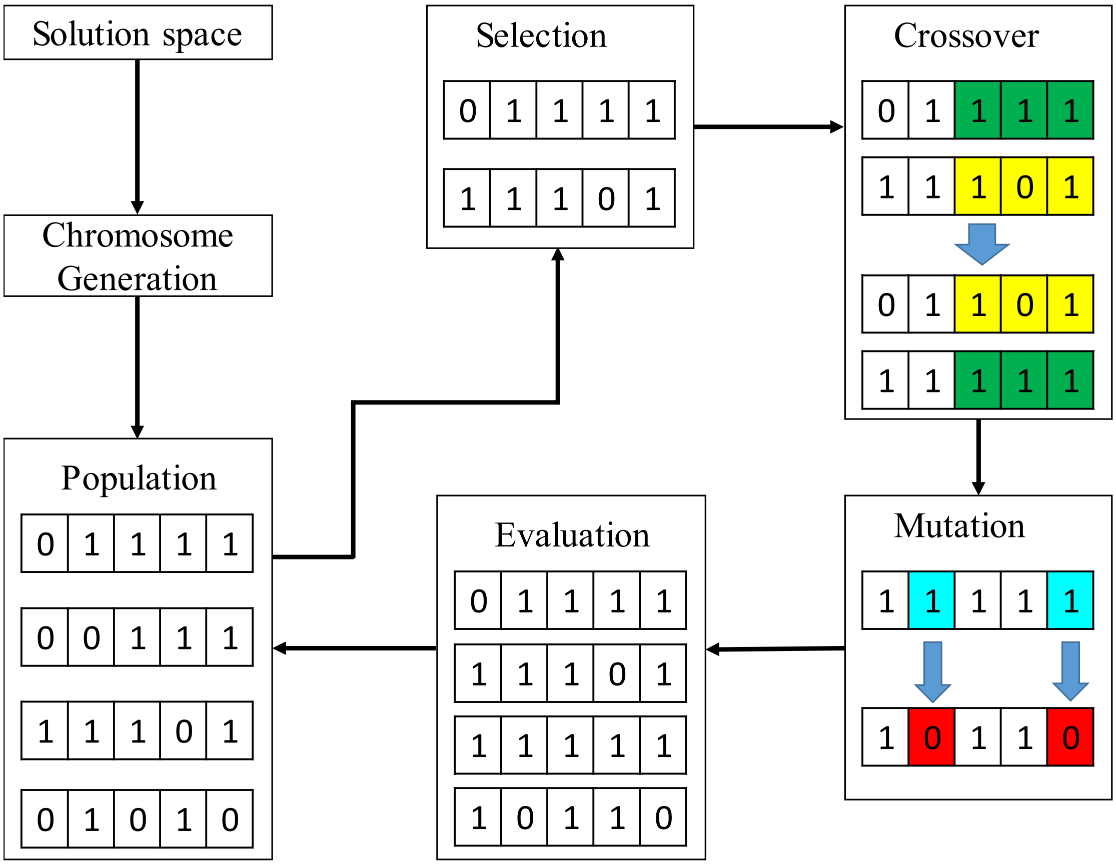


Fig. 5.9 General structure of genetic algorithm

Figure 5.9 shows the general structure of the genetic algorithm. The procedure of the genetic algorithm covering: Initialization by generating random population. Then, Selection of the individual based on the fitness function. Furthermore, the most important stage in the GA is cross over operation and mutation operation. Finally, the evaluation is required to obtain the best individual to replace or generate new offspring in a new population. The process is continue until meet the stopping criteria.

5.5 Genetic Algorithm in this Study

In this research, a genetic algorithm is used to obtain the optimum module arrangement. The detail of flow of the genetic algorithm in this thesis is described in the followings.

5.5.1 Design variables and gene representation

In this study, the basic unit of a chromosome is the arrangement information of one module for the three series ships. Figure 5.10 shows the gene sequence for a single module placement. The gene sequence is further divided into four parts; the first part is for the deck decision and the others are for module positions in the three series ships, i.e. 58BC, 82BC, 98BC, respectively. The detail of gene representation and module placement method is shown in the following.

(1) Gene representation

In this research, genetic algorithm is used as optimization method of arrangement. Therefore, the arrangement design plan is expressed using the gene sequence. The purpose of this research is to minimize costs and similarity arrangement in all series as mentioned above. Therefore, it is necessary to simultaneously arrangement of 58BC series, 82BC series, and 98BC series.

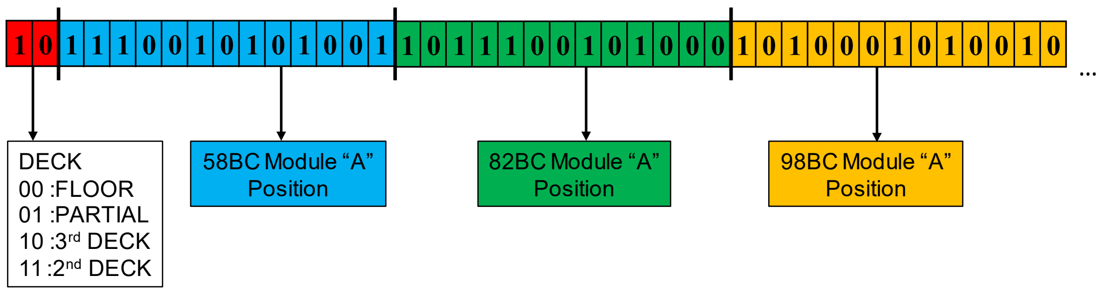


Fig. 5.10 Gene sequence of a single module

(2) Module placement method

In this research, since the same modules are arranged in three series at the same time, the arrangement plan of one module is expressed as shown in Fig. 5.10. Decks to be arranged are common to each series, and are selected from 0: FLOOR DECK, 1: PATIAL DECK, 2: 3rd DECK, and 3: 2nd DKECK is selected . Then, the module arrangement is determined from the place able area of each series.

The location of the modules based on the gene sequence is defined by the equation 5.1.

$$P = \frac{a}{c} \times b \qquad (5.1)$$

P : Arrangement place of the target module

a : Decimal value of the gene sequence

b : the allowable number of deck arrangement plan

c : The maximum value of the gene sequence (in this case, 8192)

An example of module arrangement is shown below. Consider a module having the gene sequence in Fig. 5.10 with module size is 1x1. First, it decides which deck of each module to be arranged. Since the value of the binary number is "10" here, it is decided that the module represented by the gene sequence shown in Fig. 5.10 will be arranged in the 3rd DECK of each series. (Fig. 5-12)

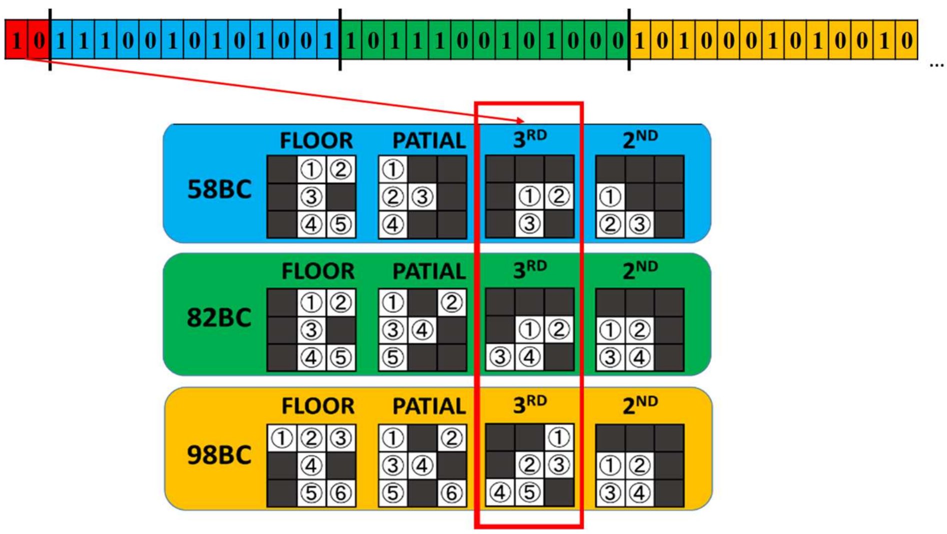


Fig. 5.11 determination of arrangement deck

Subsequently, a module in all series will be arranged in 3rd DECK. By using the equation 5.1, to decide the position or module, in the case of 58BC, the value of the binary number is "1110010101001" and when converted to decimal number is "7337", in the equation 5.1, a = 7337. In addition, since the maximum value that a gene sequence can take is "1111111111111" in binary notation and "8191" in decimal number, c is 0 to 8191, so the value of c = 8192. The candidate of allowable space in the deck is 3, so the value of b = 3.

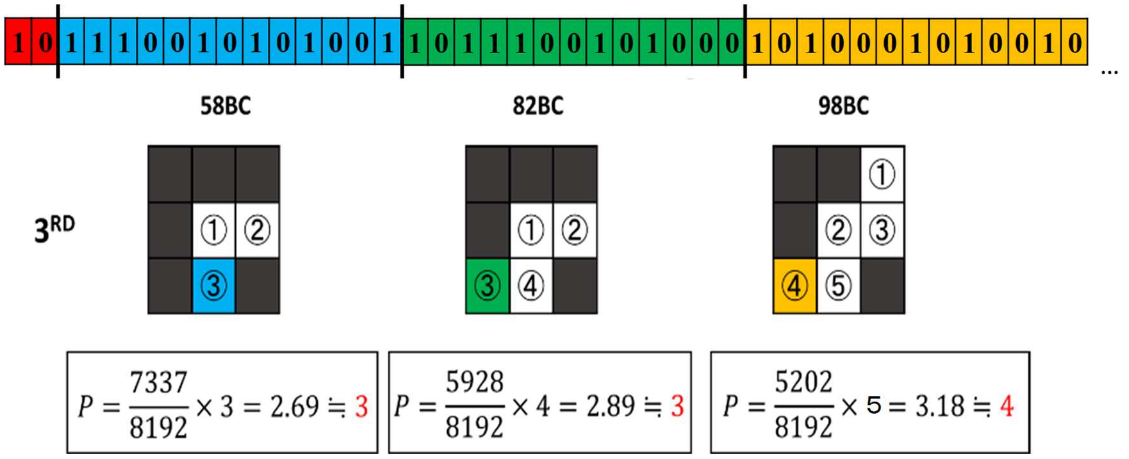


Fig. 5.12 Module arrangement

Based on the above, the position of module (P) for 58BC series is in area number 3. Figure 5.12 shows the illustration of module arrangement. Using the same way, module of 82BC series and 98BC series are determined.

The gene sequence shown in Fig. 5.10 is a design plan for one module, and by arranging the gene strings of all target modules, an arrangement design plan for all modules is generated.

5.5.2 Objective function

As previously mentioned, piping cost and similarity in arrangement for ships belonging to various series types were set as objective functions in this study.

(1) Cost calculation

In this study, the lengths of individual pipes were calculated based on the 2D calculation, height calculation and offset calculation which are shown in the followings:

- 2D calculation

2D calculation is used for the calculation of rough pipe length. The pipe length is calculated based on the following rules:

- The two extreme ends of each pipe were considered to be centers of connected modules.
- The horizontal distance and vertical distance between centers, is calculated as the pipe length as shown in Figure 5.13

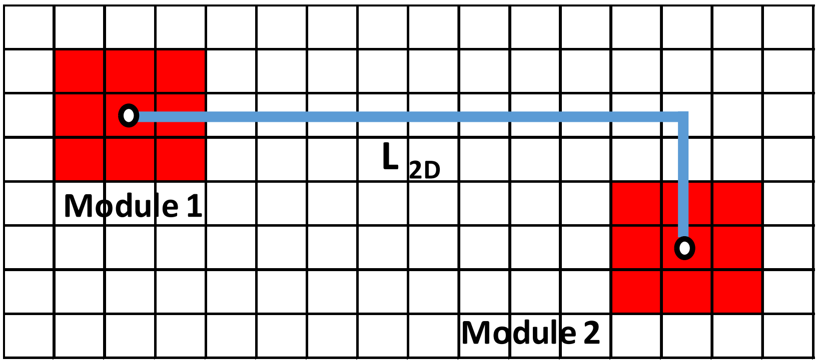


Fig. 5.13 2D calculation

- Height calculation

As shown in Figure 5.14, the height of connecting module is different and its affect the length of pipe. In this research, pipe height is calculated by equation (5.2) for same deck and (5.3) for different deck. Hence h_1 and h_2 are determined based on the past module data.

$$L_{Heigh} = |h_1 - h_2| \quad (5.2)$$

$$L_{Heigh} = deck\ \ height + h_1 - h_2 \quad (5.3)$$

h_1 : *height of module 1*

h_2 : *height of module 2*

L_{Heigh} : *pipe height between modules*

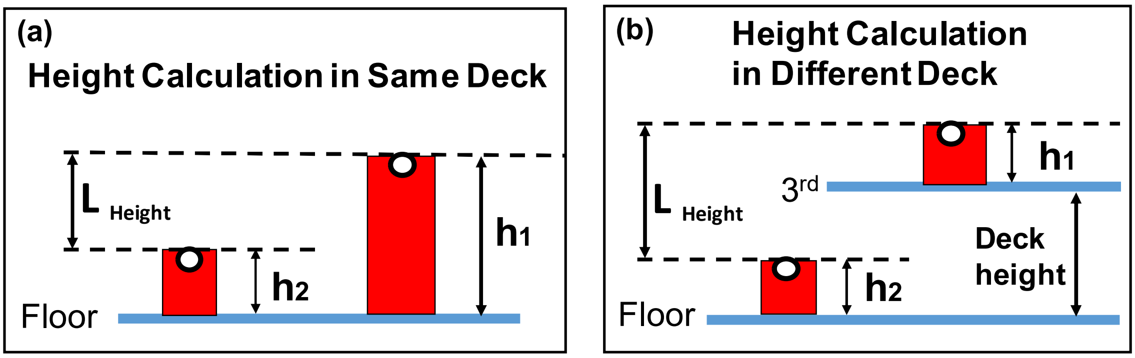


Fig. 5.14 Height calculation

- Offset calculation

As discussed in 2D calculation, center of each module is used for 2D calculation. On the other hand, actual connecting point is not the center but having offset (Figure 5.15). Figure 5.16 shows the relations between module size and offset where module size *(x)* is calculated by using equation (5.4). Then offset is decided by using the equation shown in Figure 5.16.

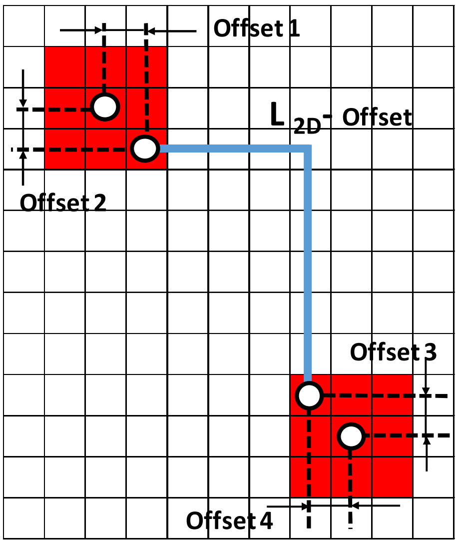


Fig. 5.15 Offset illustration

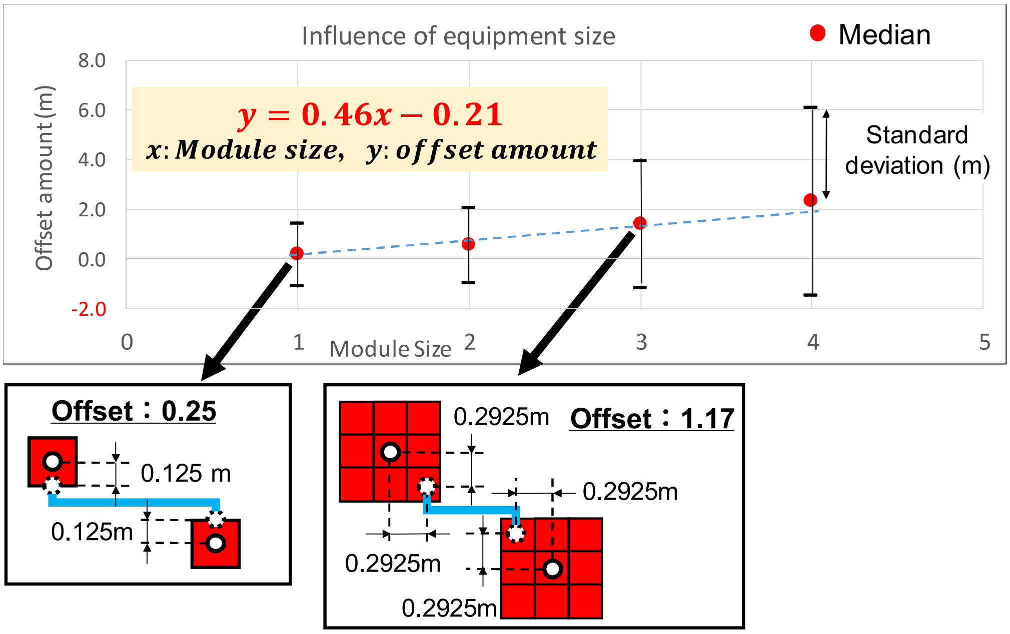


Fig. 5.16 Relation between module size and offset

$$x = \frac{R_S + C_S + R_f + C_f}{4} \qquad (5.4)$$

Rs : *rows number of starting module*

Cs : *columns number of starting module*

Rf : *rows number of finish module*

Rf : *columns number of finish module*

- Total pipe length and its evaluation

Based on the previous discussion, the total piping length is calculated by using the Equation (5.5)

$$L = L_{2D} + L_{Heigh} - Offset \qquad (5.5)$$

L_{2D} : *length using 2D calculation*

L_{Height} : *pipe height between modules*

Offset : *length of offset*

In the previous study, the calculation of piping length is focused only using the 2D calculation. However, the result is not accordance with the condition in the company. Therefore, in this dissertation, the new concept of piping length calculation is proposed. In order to evaluate the effectiveness of the new proposed method, the comparison of the correlation coefficient is required. The comparison of the correlation coefficient between piping calculation using 2D calculation (L_{2D}) and the proposed method (L) is shown in Figure 5.17.

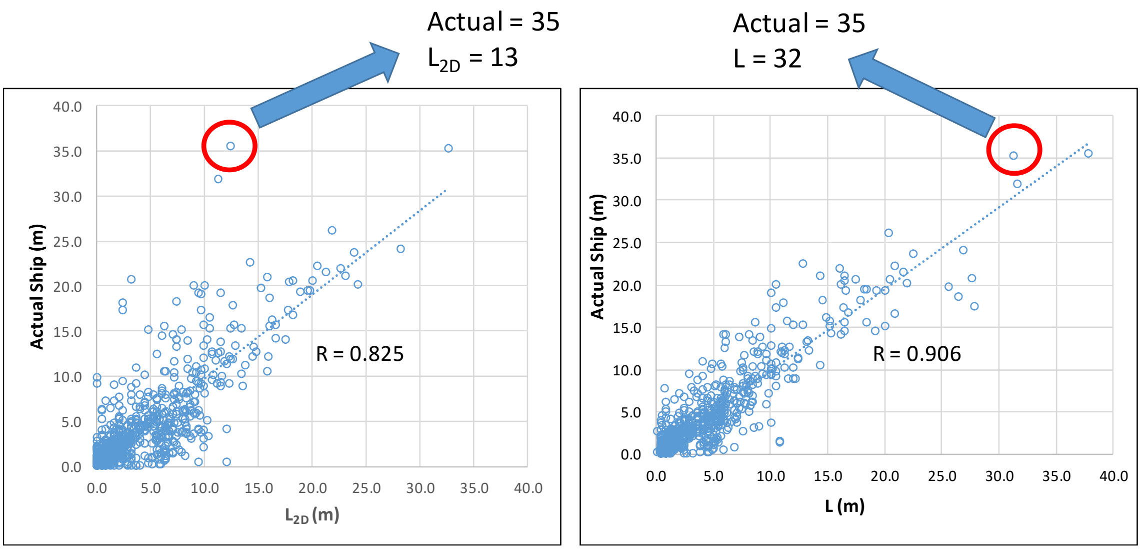


Fig. 5.17 Correlation graph comparison

Based on the Figure 5.17, the correlation coefficient is improved by using the proposed method and the estimation accuracy is improved. In the previous study, the value of correlation coefficient (R) is 0.825. However, using the new proposed method, the R value is improved in to the 0.906. On the other hand, in the real case, take the one example of the pipe length calculation, highlighted by red circle, the reference pipe length is 35 m. Using the 2D calculation, the result is 13 m. However, in the L method, the pipe length is 32 m.

Subsequent, after the pipe length calculation is obtained, therefore, cost of the pipe is calculated with considering the specific weight of the pipe.

(2) Adoption rate consideration

Adoption rate is required in order to consider the effect of optional module in the particular ship. Since the number of optional module for each ship is different, the adoption rate is most important point to be included in the cost calculation. Adoption rate is important in order to clarify the weight effect of the percentage of ship that equipped with certain optional module. In this study, for the example, only several ships are equipped with optional modules. The rate of all common modules is set as 100%. It means that the cost for each pipe connection among common module is set as 100% weight. However, the rate of optional module is lower than 100% related to the number of ships that equipped with certain optional module. Table 5.6 shows the adoption rate data for optional modules in 58BC series.

Table: 5.6 Adoption rate of 58BC series

Optional Module	Adoption Rate (%)
G/E D.O. SUPPLY PUMP	5
G.S. AIR COMP&RESEIVER	5
NO.2 F.O. HTR	2.5
FINE FILTER	35
BILGE PRIMARY TANK	30
SOOT COLLECT TANK	25
STUFFING BOX TANK	12.5

Table 5.1 shows the adoption rate data of 58BC series. In this study, the number of optional modules are seven modules. Each optional module has different adoption rate. It means that the number of ship that equipped with certain optional module is different. For the example, the number ship equipped with optional module “BILGE PRIMARY TANK” is 12 ships. However, the number ships in 58BC series is 40 ships. Therefore, the adoption rate is 12/40*100% = 30%. The adoption rate is important to decide the

optimized arrangement of the optional modules. The higher adoption rate means the higher of effect of the optional modules in the arrangement optimization.

For the example, if the cost calculation between two common module is 5, therefore, the cost in the objective function for this case is 5*40 (number of ships in the 58BC series)*100%. However, if the cost connection between certain common modules with SOOT COLLECT TANK is 8, therefore, the cost in the objective function is 8*40*25%. The adoption rate of SOOT COLLECT TANK optional module refers to the table 5.6

(3) Similarity calculation

The flow of similarity calculation is explained in the followings.

- Normalize deck

Since the deck size and arrangement area are different for the multiple series, the deck normalization is adopted. Figure 5.18 shows the deck normalization.

- Convert the coordinates of the module based on the normalized coordinates

Convert the coordinate of the module in to the coordinates normalized. At that time, the centerline of each deck is taken as a reference. Figure 5.19 shows the coordinate conversion by normalization.

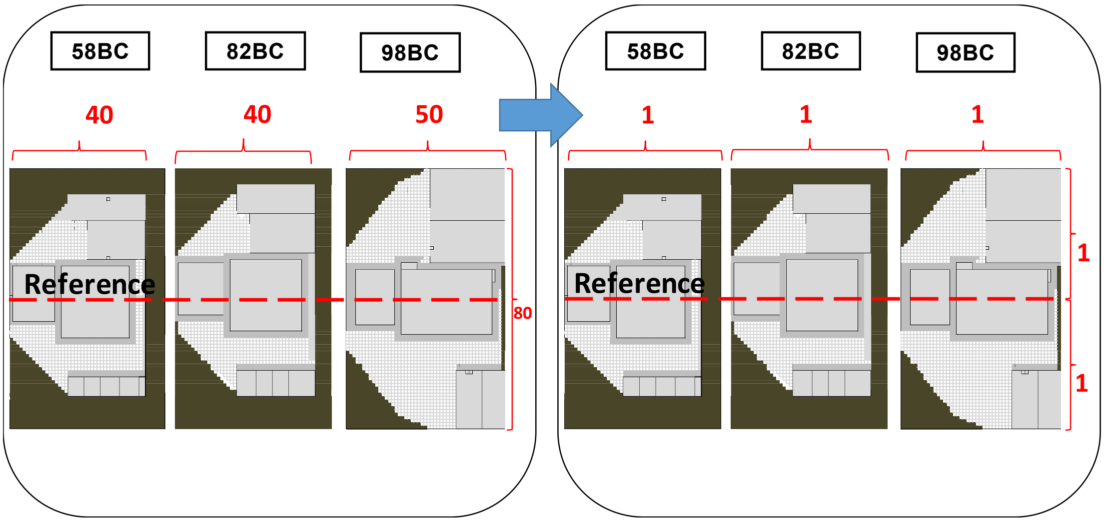


Fig. 5.18 Deck normalization

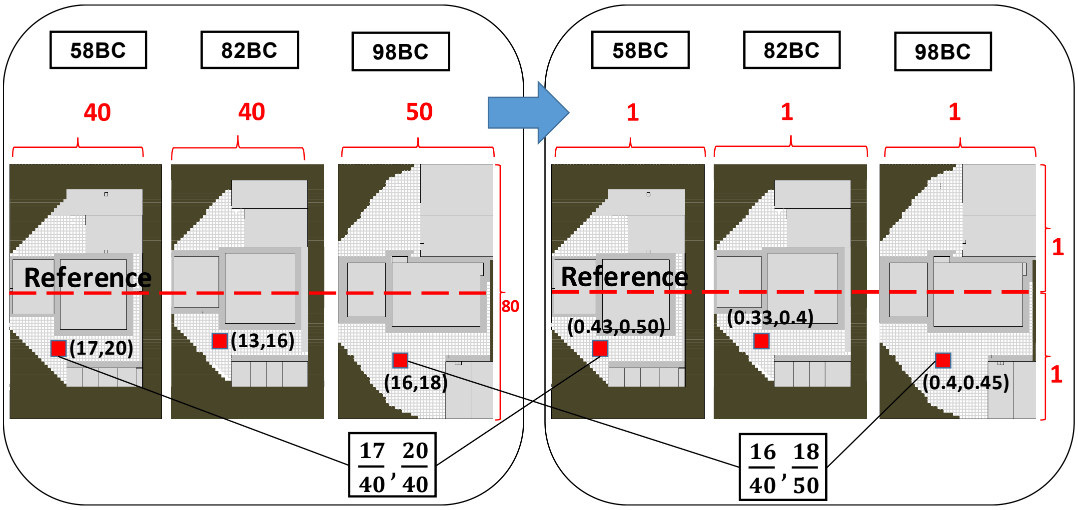


Fig. 5.19 Coordinate conversion by normalization

- Calculate distance between the same modules among each series and then make summary of the relative distance. By using the following equation.

$$\text{Similarity} = \sum\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} + \sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2} + \sqrt{(x_3 - x_1)^2 + (y_3 - y_1)^2} \quad (5.6)$$

(x1, y1) : module normalized coordinate of 58BC

(x2, y2) : module normalized coordinate of 82BC

(x3, y3) : module normalized coordinate of 98BC

The above equations represent a summary of the relative distance of one module within the normalized.

5.6 Optimization Result

5.6.1 Problem definition

To evaluate the effectiveness of our study, following optimizations were performed.

Case 1: Current arrangement in the company.

Case 2: Optimization of a single ship.

Case 3: Optimization of one series of ships.

Case 4: Optimization of ships of different sizes belonging to various series.

Bulk carrier ships with capacities of 58000, 82000, and 98000 DWT were considered as target structures in this study.

In this research, the target ship is 58BC series, 82BC series, and 98BC series. However, in this simulation, the same system diagram is used for each series, and only the module size is changed. Therefore, the connection relationship of the modules is equal for each series.

Table 5.7 shows the ID and name of the module, the module size in each series, and Table 5.8 shows the part included in the module.

Table 5.7 Module size in all series

ID	Module	Module size					
		58BC		82BC		98BC	
		R	C	R	C	R	C
1	MM1	4	6	4	6	4	6
2	MM2	5	5	5	5	6	6
3	MM3	4	3	4	3	4	3
4	MM4	1	1	1	1	1	1
5	MM5	8	3	8	3	6	6
6	MM6	6	4	6	4	6	5
7	MM7	6	3	6	3	6	3
8	MM8	4	3	4	3	4	3
9	MM9	5	2	5	2	3	2
10	MW2	2	4	2	4	2	10
11	MW3	3	3	3	3	1	2
12	MW9	1	1	1	1	1	1
13	MW10	1	1	1	1	1	1
14	MW11	2	1	2	1	3	3
15	MW12	2	1	2	1	3	3

16	MW13	1	1	1	1	1	1
17	MW14	1	1	1	1	1	1
18	MW15	1	1	1	1	1	1

Table 5.8 Part in module

ID	Module	Part in module
1	MM1	MAIN COOLING F.W. COOLER, F.W. GENERATOR, EJECTER PUMP, M/E PRE-HTR
2	MM2	ATOMOS CONDENCER, CASCADE TK, HYD UNIT)
3	MM3	NO.1,2 AUX COOL F.W. COOLER
4	MM4	G/E F.O. COOLER
5	MM5	F.O. CLR, F.O. HTR, NO.1,2 F.O. CIRC PUMPS, F.O. RETURN OIL RECEIVER
6	MM6	NO.1,2 MAIN AIR COMPRESSOR
7	MM7	NO.1,2 F.O. PURIF, NO.1,2 PURIF F.O. HTR
8	MM8	SHIFT F.O. HTR, F.O. SHIFTER PUMP
9	MM9	G/E F.O. 2ND FILTER, M/E F.O.2ND FILTER
10	MW2	NO.1,2 MAIN COOL S.W. PUMP
11	MW3	REACTION TK OF M.G.P.S
12	MW9	Branch, valve
13	MW10	Branch, valve
14	MW11	FIRE & BILGE PUMP
15	MW12	FIRE & G.S. PUMP
16	MW13	Branch, valve
17	MW14	Branch, valve
18	MW15	Branch, valve

5.6.2 Parameter of optimization

The important points in the optimization are described below.

- All series optimized simultaneously.
- Target ship is 40 ships of 58BC series, 55 ships of 82BC series and 5 ships of 98BC series.
- The objectives function are cost minimization and similarity arrangement.
- Parameters in optimization:
  - Number of generations: 2000
  - Number of populations: 100
  - Selection: tournament selection
  - Crossover: one point crossover
  - Mutation rate: 3%

5.6.3 Arrangement result

In this chapter, the result of the arrangement optimization is depicted. The arrangement optimization is addressed to optimize the single ship, one series ships, and various series ships. However, the initial arrangement before the optimization is required in order to make the comparison of the arrangement. The current arrangement is designed and provided by the Tsuneishi shipbuilding company based on the experience of the engineer and some requirements from the owner.

Subsequent, the effectiveness of the arrangement result is evaluated using the arrangement requirements as denoted in the chapter 3.3.2 such:

- Various constraints such as the space requirement for maintenance, area for fixed components, etc. should be considered.
- Similarity of arrangements should be considered for a single ship, series ships, and for various types of series ships.

- Pipe costs should be minimized with respect to the pipe length, diameter, material, etc.

The detailed of the explanation of effectiveness is explained in the chapter 5.7

(1) Current arrangement in the company

The current arrangement in the company is depicted in Figure 5.20. The arrangement is different both for each ship in one series and for each series. The arrangement is different because the arrangement is optimized for each ship based on the experience of the engineer. The current arrangement is the arrangement design before conduct the optimization as proposed in this dissertation. In addition, this arrangement is provided by the company. In this case, four ships are carried out in order make the comparison of module arrangement. Based on this Figure, the arrangement of each ship in different series is different. Moreover, the arrangement is ship A and ship B is different, even though ship A and ship B are the same series.

The difference arrangement of each ship induce some disadvantages such as: increase the design cost, increase the design time and increase the mistake of the construction.

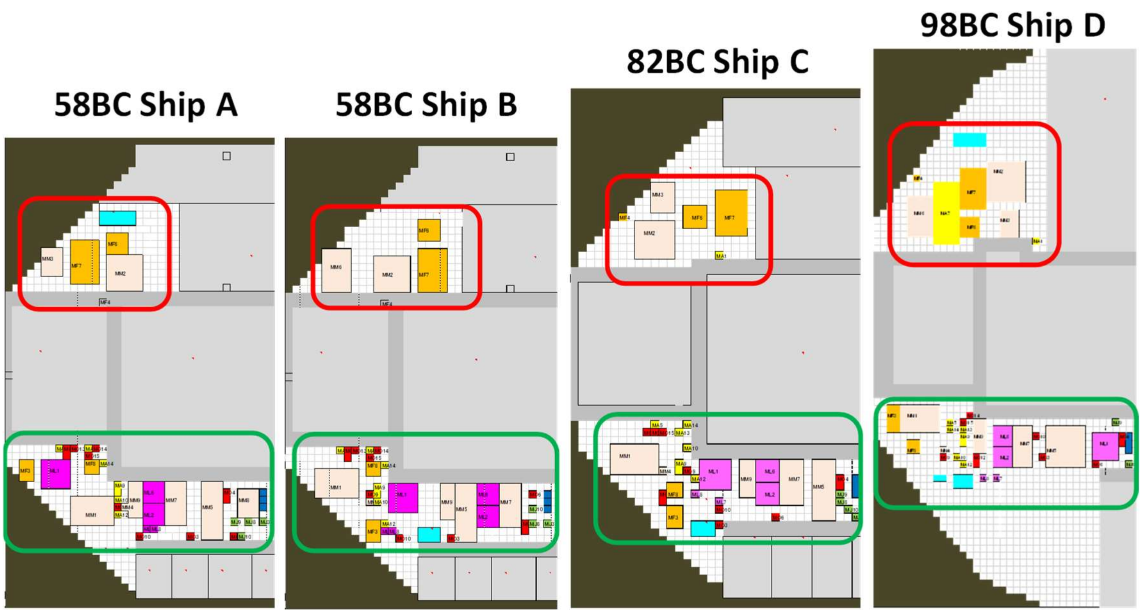


Fig. 5.20 Current arrangement in the company in 3rd Deck

(2) Optimization result

To solve the above optimization problem, a genetic algorithm (described in a foregoing section) was adopted. The time taken by the optimization program to perform necessary calculations was approximately 3 hours. The optimization result is divided into three categories; individual ship, one series ships and various series ships. The convergence history for which is illustrated in Figure 5.21. The result of the optimization operation (case-4) is depicted in Figure 5.22. As shown in the figure, modular arrangements of all three series of ships are generated in a single optimization run.

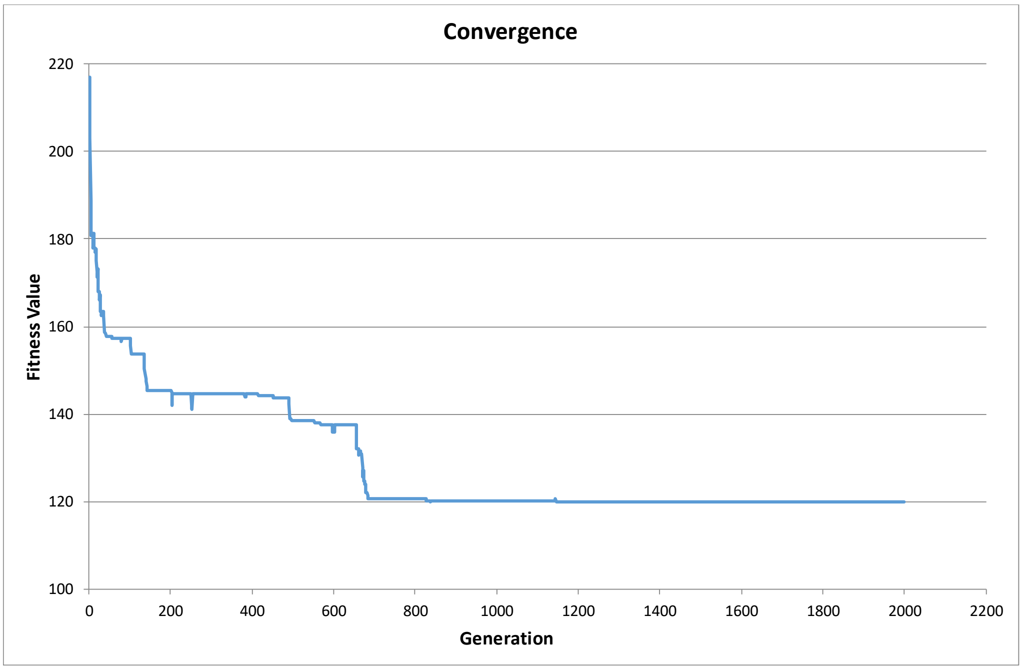


Fig. 5.21 Graph of convergence

Figure 5.21 shows the convergence of this optimization. This graph illustrates the relation between fitness value with the number of generation. This result is the optimization for various series ships. Based on this Figure, it can be said that the convergence is occurred around the 800 generation. After the generation reach the 1200, the fitness value is looked constant. The rate of convergence is caused by the how complicated of the optimization problem, how many number of population and the complexity of the objective function.

Figure 5.22 shows the optimization result of the case-4 (various series ships). The completed result of three decks level is depicted this Figure. The arrangement of all modules looked similar in case of three various series ships.

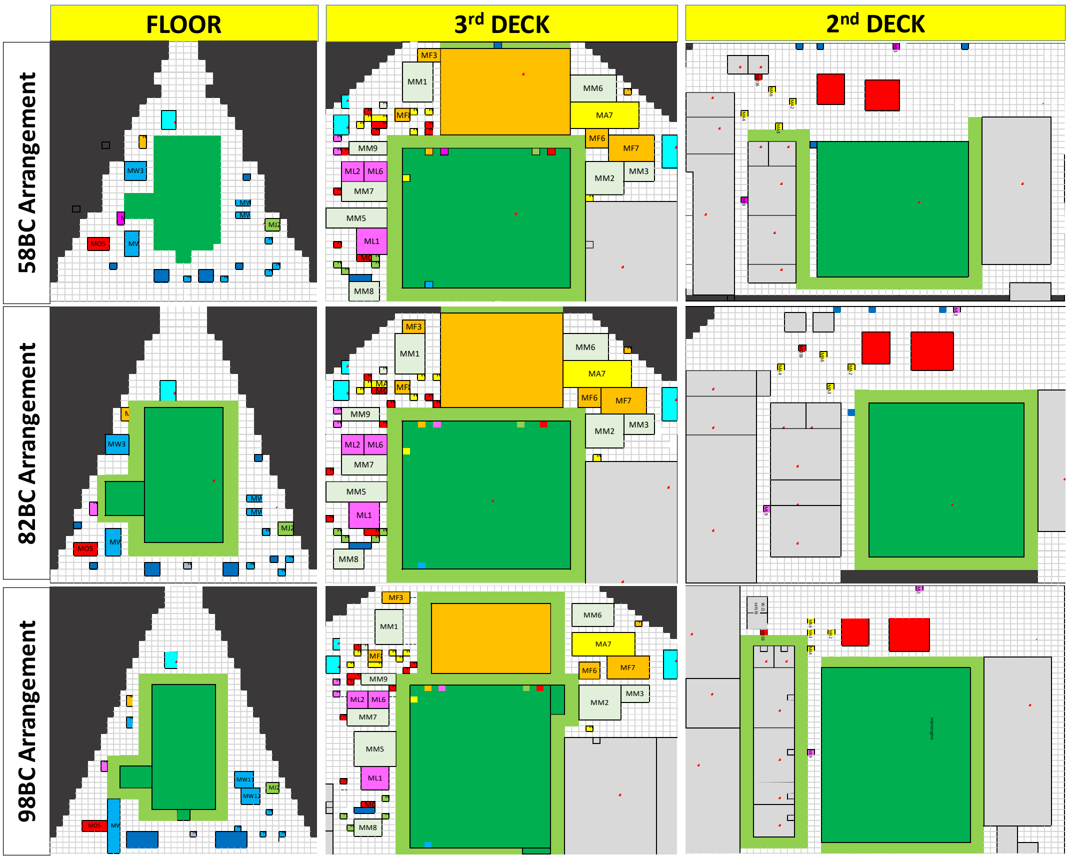


Fig. 5.22 Optimization result of case-4

(3) Optimization of a single ship

The optimization result for each ship (case-2) is depicted in Figure 5.23. In this case, the optimization is executed one by one for each ship. In this case, four ships are conducted to identify the arrangement result. Based on this Figure, the arrangement for each ship is different. Although in the different ship in same series, the arrangement is different. In Figure 5.23, ship A and ship B are the example of 58BC series. However, the arrangement is different in floor, 3rd deck and 2nd deck.

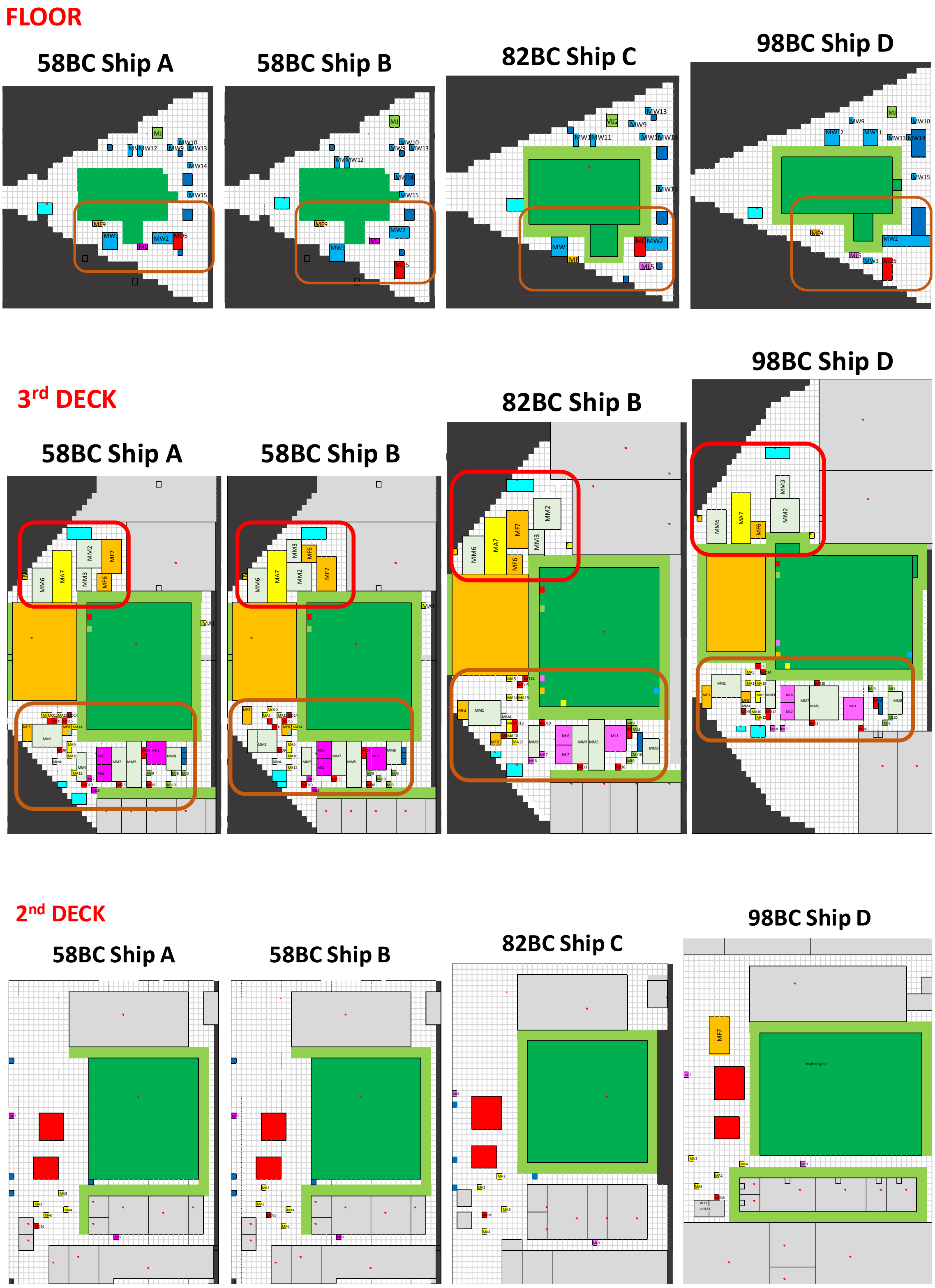


Fig. 5.23 Optimization result of case-2

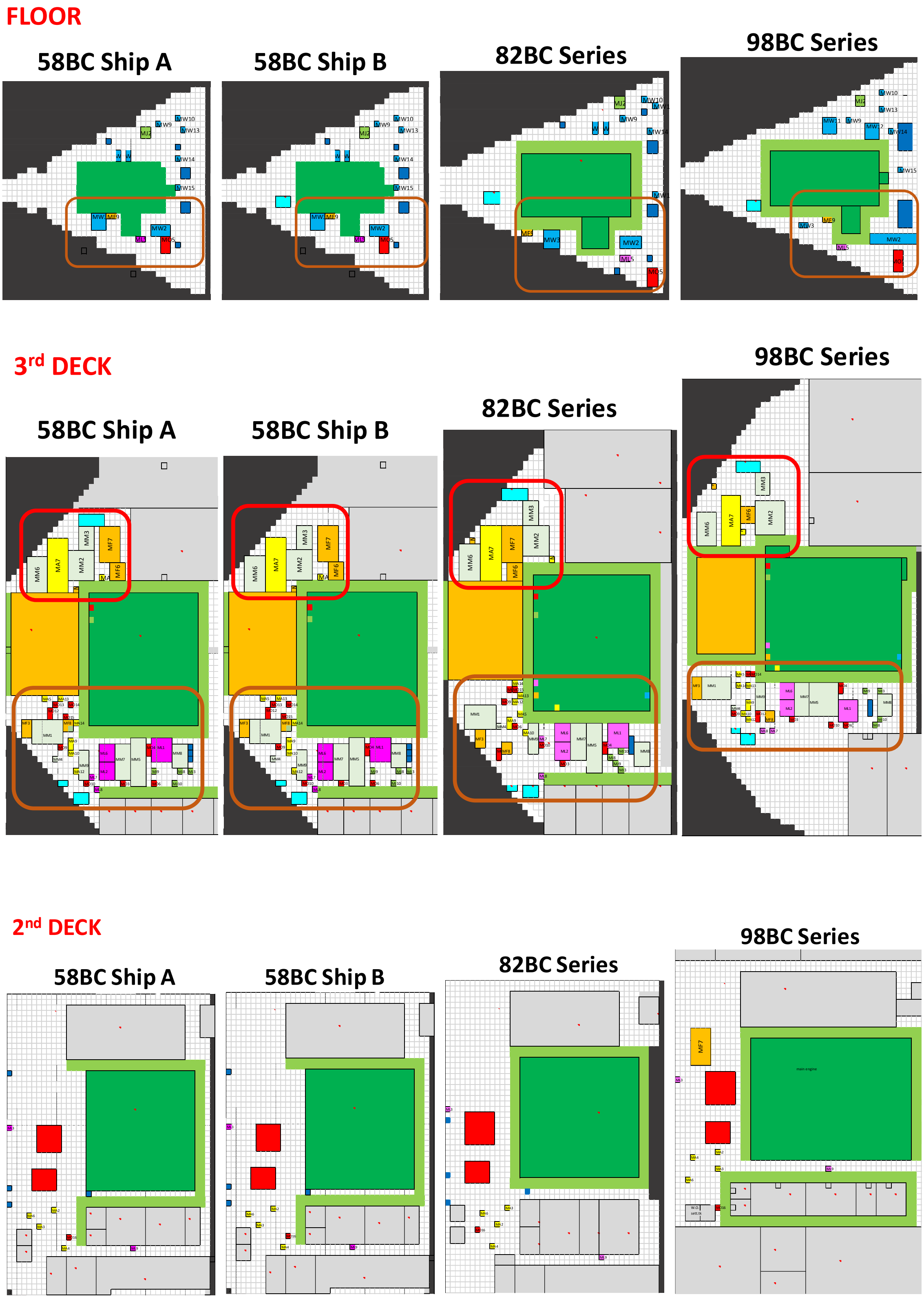


Fig. 5.24 Optimization result of case-3

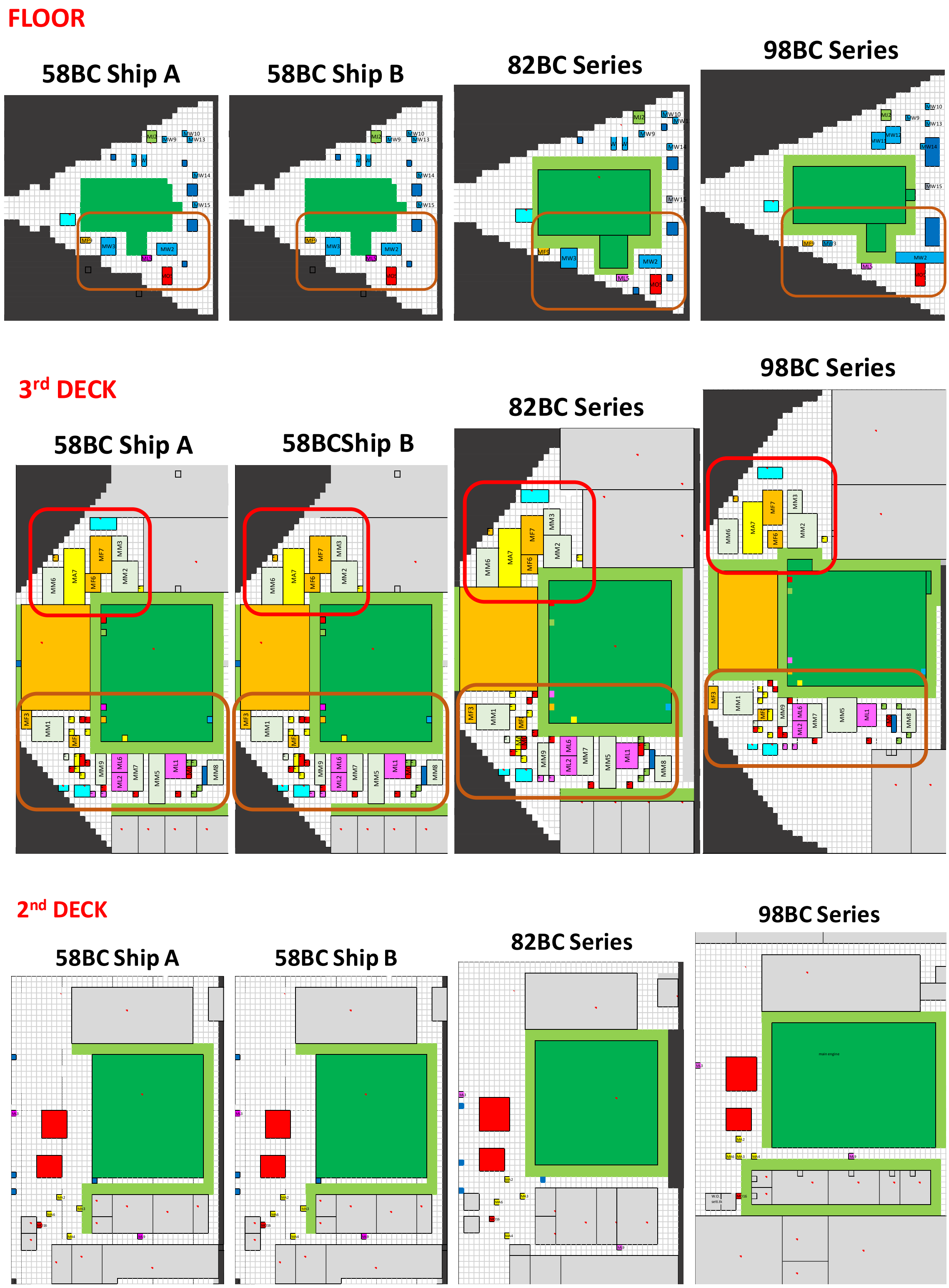


Fig. 5.25 Optimization result of case-4

(4) Optimization of each series ships

The optimization result for each series (case-3) is depicted in Figure 5.24. In this case, the optimization is simultaneously for all ships in the same series. The arrangement of each ship in the same series is same. For the example, ship A and ship B are the same series. Therefore, the arrangement of ship A and ship B is same. However, the arrangement in different series is different.

(5) Optimization of various series ships

The optimization result for various series (case-4) is depicted in Figure 5.25. In this case, the optimization is executed simultaneously for all ships in all series. As the result, the arrangement of all ships in all series is similar. The similarity arrangement is obtained for all series ships in terms of floor, 3rd deck and 2nd deck. The similarity arrangement is obtained because the optimization process is executed in one time including cost minimization and similarity calculation as the objective function.

5.6.4 Cost result

The arrangement optimization comprises of two important points as include in the objective function. First, is pipe cost minimization and second is similarity arrangement. The similarity arrangement is explained in the chapter 5.5.3. Furthermore, the cost minimization is required in order to fulfilled the objectives.

Cost of the pipe is combination of the pipe length, pipe weight and the material of the pipe. The cost comparison of Cases 1–4 is depicted in Table 5.9. The cost for Case 1 were set as 100. As observed in the table, Case 2 is the most optimum in terms of cost. However, there are very slight differences between corresponding values for Cases 3 and 4 in comparison to Case 2.

Table 5.9 Cost comparison

COST RESULT	58BC	82BC	98BC
CASE 1	100	100	100
CASE 2	97.77	97.25	98.38
CASE 3	97.94	97.63	98.55
CASE 4	98.15	97.87	98.77

Cost reduction for each series is different. Based on the Table 5.9 above, the 82BC series is the best result. The cost reduction for each series is obtained by the comparison of cost after optimization with current arrangement. Whereas, the current arrangement in the company is different for each series. Therefore, the cost reduction of each series is strongly related to the current arrangement data from the company. Furthermore, the cost reduction is affected by the module data and engine room layout data.

5.7 Evaluation of the Arrangement Result

This chapter explained the effectiveness of the arrangement due to the some arrangement requirements as denoted in the chapter 3.3.2. The explanation of these effectiveness is listed in the followings:

(1) Various constraints such as the space requirement for maintenance, area for fixed components, etc. should be considered.

The module arrangement should be considered the various constraints. In this case, the arrangement result is fulfilled with this requirements. Figure 5.26 shows the arrangement plan.

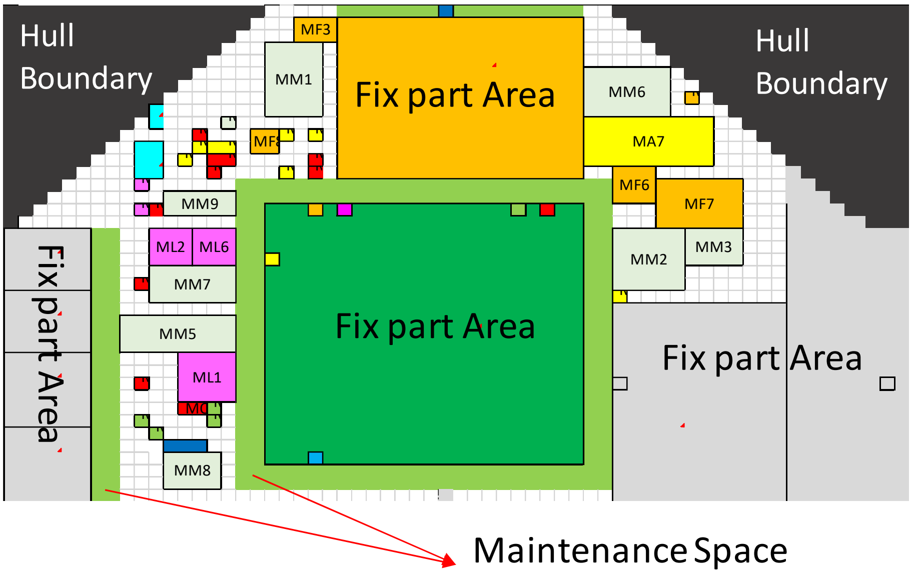


Fig. 5.26 Module arrangement

Figure 5.26 shows the module arrangement in certain deck. This deck area consists of some constraints such as area for fix part, area for maintenance and the hull boundary. Modules are not allowed to arrange ion these areas. According to the above Figure, all modules arranged in the module placement area, no modules are arranged in the restricted area.

(2) Similarity of arrangements should be considered for a series ships, and for various types of series ships.

The similarity arrangement is the most important point in the arrangement optimization. Due to the above requirement, the result of arrangement optimization is obtain the similarity arrangement in case of each ship in one series and each ships in all series. The illustration of the similarity in one series is depicted in the figure 5.24. Furthermore, the illustration of the similarity arrangement in all series ships is depicted in the Figure 5.25.

(3) Pipe costs should be minimized with respect to the pipe length, diameter, material, etc.

The arrangement optimization not only consider the similarity for all series but also consider the minimized pipe cost. Pipe cost is important in term of the total production cost of the piping system due to the pipe length, pipe diameter and pipe material. Table 5.9 shows the comparison of pipe cost in all cases.

The cost for Case 1 were set as 100. As observed in the table, Case 2 is the most optimum in terms of cost. However, there are very slight differences between corresponding values for Cases 3 and 4 in comparison to Case 2. The result of the pipe cost in the optimization result (case 2 through case 4), is lower than cost in current arrangement. In can be concluded that the arrangement is effective in terms of the cost calculation compare to the current arrangement in the company.

The cost for case 2 is the most optimum compare to the other cases. It means that if the design is adopted only for one ship production, result of case 2 is better than case 4. However, in this study, the production concept is consideration the various series ships with more than 100 ships were built, therefore the arrangement design of case 4 is more effective than case 2. For the example, in 82BC series, the cost reduction of case 2 is 2.75% and cost reduction of case 4 is 2.13%. Off course, case 2 is better than case 4 in term of this design is adopted for one ship production. However, in case of 82BC series, there are 55 ships were built, therefore if concept of the case 2 is adopted, consequently, designer have to create 55 times of the design. Therefore, the total time and total cost increase drastically. Using the all series optimization concept (case 4) in case the cost reduction is lower than case 2, however, the designer just need one time to design 55 ships. It can be said that, in term of case 4, the total cost for design 55 ships is lower than case 2.

5.8 Conclusions of the Arrangement Result

Development and implementation of an optimization system of module arrangement, has been discussed in this chapter. Followings are the conclusions of the chapter.

(1) Flow of optimization of the module arrangement design is discussed in detail.

(2) Genetic algorithm is used in this study.

(3) Optimization is executed simultaneously inconsideration of one series ships and various series ships.

(4) Similarity arrangement is considered in order to obtain standard design for various series ships.
(5) Pipe cost minimized is considered as the objective function besides the similarity calculation.
(6) Result is evaluated using the requirements and the current arrangement design provided by the company.

Chapter 6

Discussion

6.1 Comparison of Optimization Results

This section describes the comparison of optimization result. There are two important points in the optimization: cost and arrangement. Cost result and cost reduction for each series is depicted in the table 6.1. According to the table 6.1, the cost reduction for each series is different. However, for 58BC series and 82BC series, the result of cost reduction is rather similar. Based on the Table 6.1, the cost reduction of 98BC series is lower than 58BC series and 82BC series. The cost reduction for each series is obtained by the comparison of cost after optimization with cost in the current arrangement. Therefore, the cost reduction of each series is strongly related to the current arrangement data from the company.

Table 6.1 Cost result and reduction of case 2 – 4

COST RESULT (%)	58BC	82BC	98BC
CASE 1	100	100	100
CASE 2	97.77	97.25	98.38
CASE 3	97.94	97.63	98.55
CASE 4	98.15	97.87	98.77
CASE 2 (reduction)	**2.23**	**2.75**	**1.62**
CASE 3 (reduction)	**2.06**	**2.37**	**1.45**
CASE 4 (reduction)	**1.85**	**2.13**	**1.23**

The cost reduction of 98BC series is the smallest one. In 58BC series and 82BC series, the module arrangement in the current arrangement is very different with the optimization result. However, in the 98BC series, the arrangement change is not significance. The cost reduction is calculated from the comparison of optimized cost with current arrangement cost. Since the current arrangement is not too different with optimized arrangement, the cost reduction is relatively small. The illustration of piping cost calculation for 82BC series and 98BC series is depicted in the figure 6.1

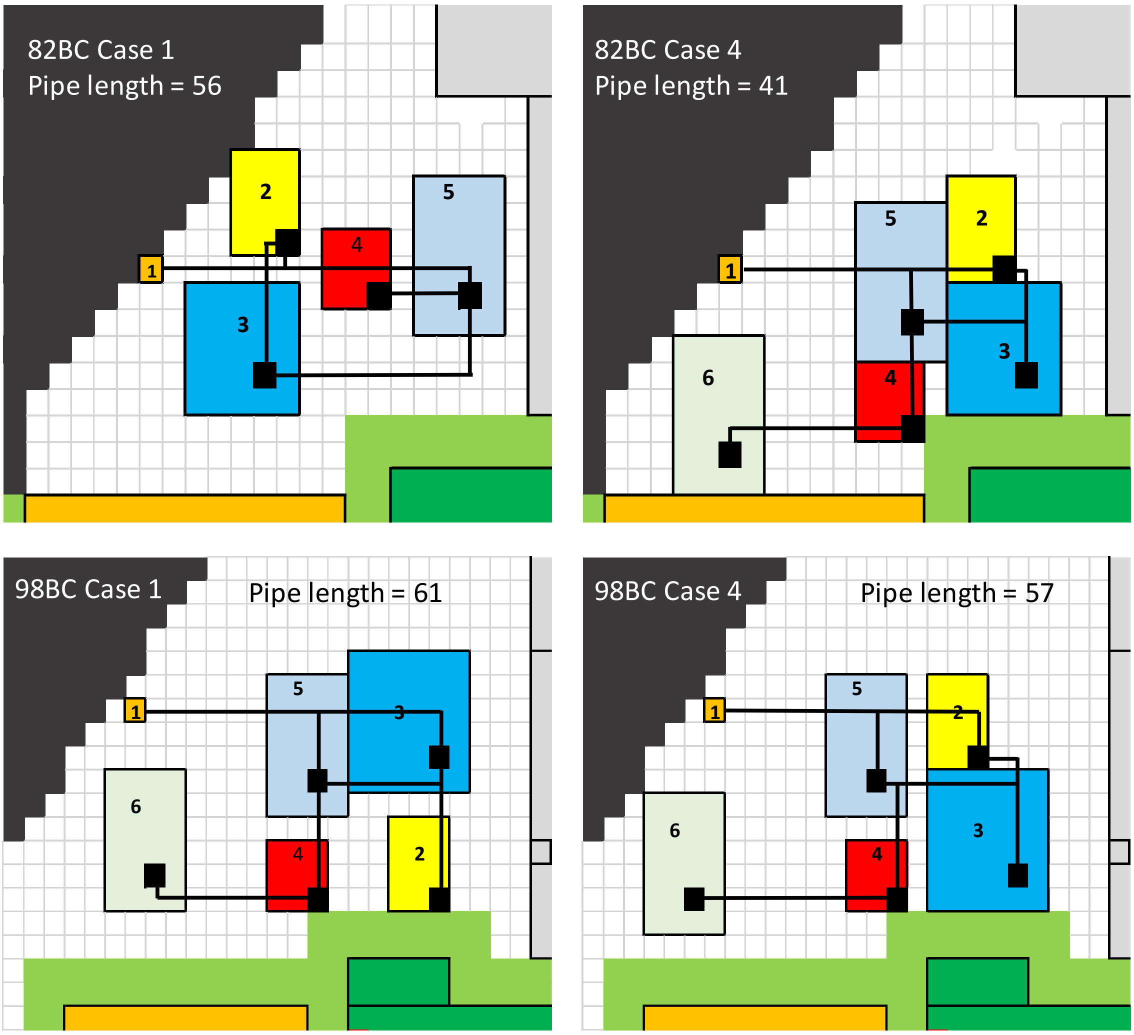


Figure 6.1 Module arrangement in 3rd DECK Portside of case-1 and case-4 in 82BC series and 98BC series

Figure 6.1 illustrates the comparison of arrangement before optimization and after optimization. Based on the above figure, the pipe length reduction of 82BC series is better than in 98BC series. In the 82BC series, module arrangement before optimization looked separate by some free area. However, after optimization, the module arrangement change to adjacent position for each other. In the other hand, module number 6 is arranged in the different deck; therefore, the pipe length connection between module number 4 and number 6 is longer than after optimization.

In the 98BC series, the configuration module arrangement seems similar before optimization and after optimization. It can be said that the current arrangement of 98BC series is better than in 82BC series. The difference of the current arrangement for each series might be caused from the different ability of the engineer to arrange module position according to the available free space area and some constraint conditions. The little change of the arrangement before optimization and after optimization makes the pipe length reduction of 98BC series is smaller than 82BC series and 58BC series. Based on the Figure 6.1, the current arrangement of 98Bc series comprises 6 modules in the same deck. However, in 82BC series, module number 6 is arranged in the different deck.

6.2 Effectiveness of Module Design

Based on the table 6.1, the cost for case 2 is the most optimum compare to the other cases. This condition means that the result of case 2 is better than in case 3 and case 4 if the cost calculation only consider the design cost for each ship. However, in the real condition, the construction cost should be considered to explain the total effectiveness of the module design. In the other hand, in this study, the various series ships concept with more than 100 ships is decided as the target ship. Refers to the table 6.1, in 82BC series, the cost reduction of case 2 is 2.75% and cost reduction of case 4 is 2.13%. Off course, case 2 is better than case 4 in term of design cost for one ship. In this study, there are 55 ships in the 82BC series. Consequently, if the concept of case 2 is adopted, designer have to design 55 times. Therefore, the total design cost increase drastically. However, using the case 4 concept (all series optimization), designer just need one time to design 55 ships.

Furthermore, the calculation of total cost including construction cost in series ships concept will be explained in this chapter. According to the reference study, in the engine room area, the piping design process requires about 10% of design, 25% of material and 65% of construction cost. The problem formulation to compare the total cost calculation between case 2 and case 4 is depicted in the table 6.2. Furthermore, the result of calculation is illustrated in the table 6.3. In the case 2, the cost reduction of piping design in the engine room is 2.75% for 82BC series. However, in the case 4, the cost reduction is only 2.13%. Off course, case 2 is better than case 4. However, in the case 2, the design is executed one by one. The total cost calculation including design cost, material cost and construction cost inn one ship case and series (100 ships) case is illustrated in the table 6.3.

Table 6.2 Problem formulation to calculate total cost

	Design	**Material**	**Construction**
Case 2	100 times	100 ships	100 ships
Case 4	1 time	100 ships	100 ships
Cost	**10%**	**25%**	**65%**

$$\textbf{Case 2} = \frac{(\textit{Design Cost x } 100)+(\textit{Material Cost x } 100)+(\textit{Construction Cost x } 100)}{100}$$

$$\textbf{Case 4} = \frac{(\textit{Design Cost x } 1)+(\textit{Material Cost x } 100)+(\textit{Construction Cost x } 100)}{100}$$

Table 6.3 Total cost calculation analysis of piping design and construction

Total Ship	Case 2 (Cost)			Case 4 (Cost)		
	Design	Material	Construction	Design	Material	Construction
1 Ship	100	97.25	100	100	97.87	100
Total Cost	**99.31**			**99.47**		
Series	100	97.25	100	1	97.87	100
Total Cost	**99.31**			**89.56**		

Table 6.3 illustrates the cost calculation analysis in engine room for design cost, material cost and construction cost. In this table, the comparison of cost analysis between case 2 and case 4 is described. In case of build 1 ship, the cost calculation for case 2 is lower than case 4. However, when this concept is adopted in the series ships, the cost for case 4 is better than in case 2. In the case 2, off course the material cost is lower than case 4, however, if there are many ships were be built, the design cost only one time. In the case 2, in order to build 100 ships, the design cost is multiple by 100 times.

In the single ship production, total cost reduction including design cost, material cost and construction cost for each ship is 0.69% in case 2. However, total cost reduction for single ship production is 0.53% in case 4. In can be said that, in the single ship production concept, case 2 is better than case 4 in term of total cost reduction. However, by considering the series ships concept (building 100 ships), the cost reduction in case 4 increase up to 11.44%. In other word, case 4 is better than case 2 in consideration of series ships production.

6.3 Effectiveness of this Study

In this study in order to obtain the piping design optimization, the two important aspects: modularization and arrangement are explained. Modularization is effective strategy in order to solve the complexity of the piping system. In this case, DSM is adopted to modularize the all parts in piping system. The important point in the modularization is used the commonness modularization concept. Module should be separately between common and optional. Using the commonness modularization, the result is effective based on the evaluation by the requirements.

Subsequent, the next important aspect is optimized arrangement. In order to obtain the optimized arrangement, genetic algorithm is adopted. In the module arrangement, the two important points are cost minimization and similarity arrangement. Similarity arrangement is pay attention to because the target ship of this study is various series ships. Figure 6.2 demonstrates positions of modules (3rd deck on the portside) corresponding to

Cases 2–4 for the three series of ships. As shown in the figure, modular positions for the three series of ships are different for Cases 2 and 3. However, in Case 4, modular positions for the three series of ships are almost similar although the size of their corresponding modules and decks are largely different. Case 4 has a similar arrangement because the data for all of the series of ships were optimized at the same time and included a similarity calculation as a part of the objective function. A similar arrangement has been found to be beneficial in terms of maintenance and design/production lead time. Therefore, Tsuneishi Shipbuilding Co., Ltd, employed the proposed arrangement for designing their ship.

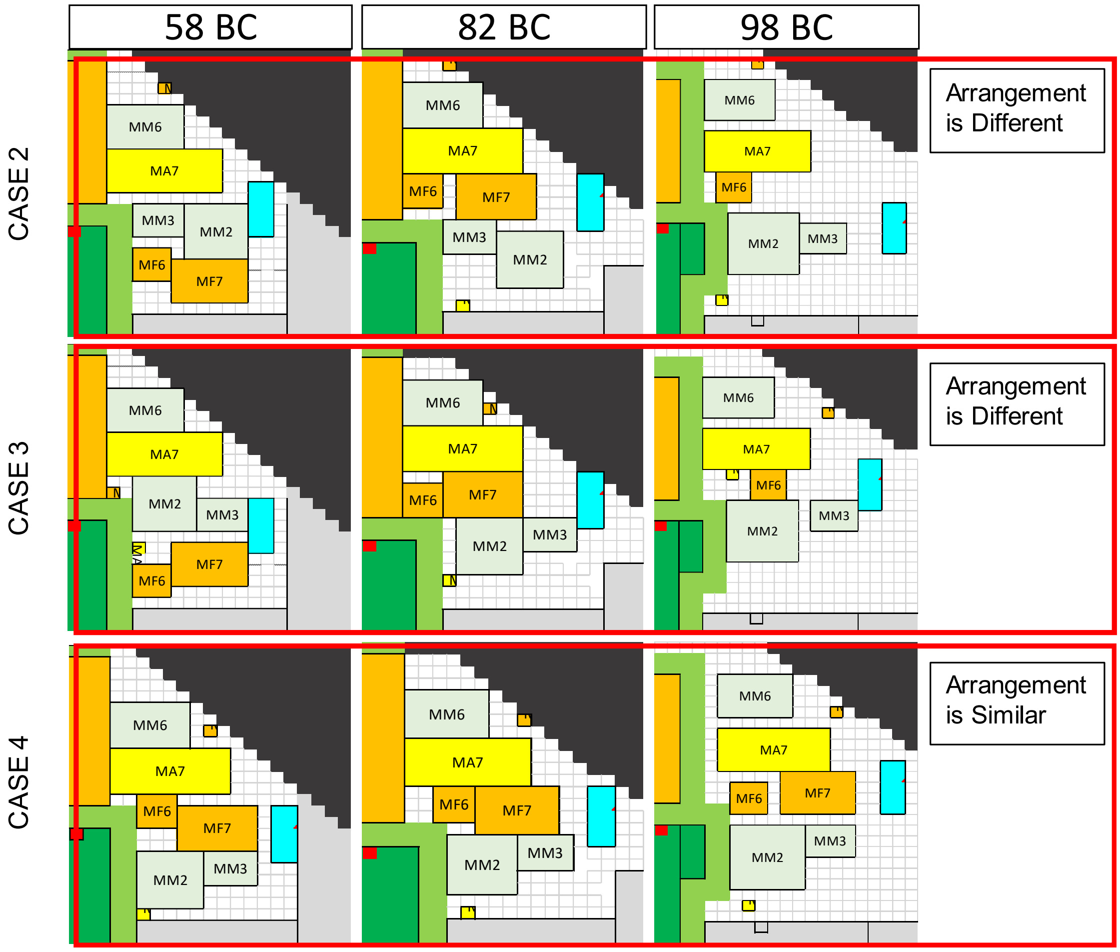


Fig. 6.2 Different of optimized arrangements on the 3rd deck in three cases

In the standpoint of the ship owner, the common arrangement have some beneficial aspects such as: easier in the maintenance activity, easier in the operation activity, and easier in the familiarization of the engine room crew. The ship owner company possible to change the engine room crew because the characteristic and the location of equipment is similar for each ship.

Therefore, the following characteristics of the proposed methodology are important to obtain the optimum arrangement of a series of ships.

- The piping data for all series of ships are collected and the modularization using DSM is carried out at once considering the common parts and optional parts.
- The optimization of arrangements for the various types of series ships are executed simultaneously.
- In addition to the cost, the similarity of the arrangements is considered and is set as the objective function.

6.4 Robustness of the Optimization Results

The optimization method is this study using the Genetic Algorithm. This method can be can be classified as being probabilistic populations based optimizers. The probabilistic nature of the search suggests that GA's may lack robustness in finding solutions. Further, it is a common perception that since GA's iterate on a population (set) of solutions, they require many simulations to converge. The robustness of the algorithm is examined in terms of the variability of the final solutions from each set of simulations.

In order to examine the robustness of this GA in finding arrangement optimization, there are 3 cases in the simulation. Table 6.4 shows the objective plan to examine the robustness of the result. In this study, case 1 is the arrangement from the company. Case 2 is the arrangement of each ship optimization. Then, the arrangement of each series optimization is depicted in the case 3. Finally, case 4 is the arrangement of the various series optimization. Based on the table 6.4, the cost analysis of case 2 and case 3 will be evaluated in the different target ship. For the example, in the case 2, the best arrangement in term of cost calculation is 82BC series which has value 97.25. The arrangement of case 2 in 82BC series will be evaluated with 58BC and 98BC of target ship. Likewise, the arrangement plan of 58BC and 98BC will be evaluated in the other target ship. Table 6.4 shows the objective method to evaluate the robustness of each case. Therefore, the evaluation method is adopted in the case 3. In case 4, each arrangement plan is similar for all series, therefore, the evaluation is not needed.

Table 6.4 Objective of the robustness result

Objective Value		**Target Ship**		
		58BC	**82BC**	**98BC**
Case ①	Opt Arrangement of 58BC	100	-	-
	Opt Arrangement of 82BC	-	100	-
	Opt Arrangement of 98BC	-	-	100
Case ②	Opt Arrangement of 58BC	97.77	?	?
	Opt Arrangement of 82BC	?	97.25	?
	Opt Arrangement of 98BC	?	?	98.33
Case ③	Opt Arrangement of 58BC	97.94	?	?
	Opt Arrangement of 82BC	?	97.63	?
	Opt Arrangement of 98BC	?	?	98.55
Case ④		98.15	97.87	98.77

The illustration of the evaluation arrangement in the different target ship is provided in the Figure 6.3. This Figure shows the comparison of four cases arrangement plan. Each arrangement in case 2 and case 3 will be evaluated the robustness using the different target ship.

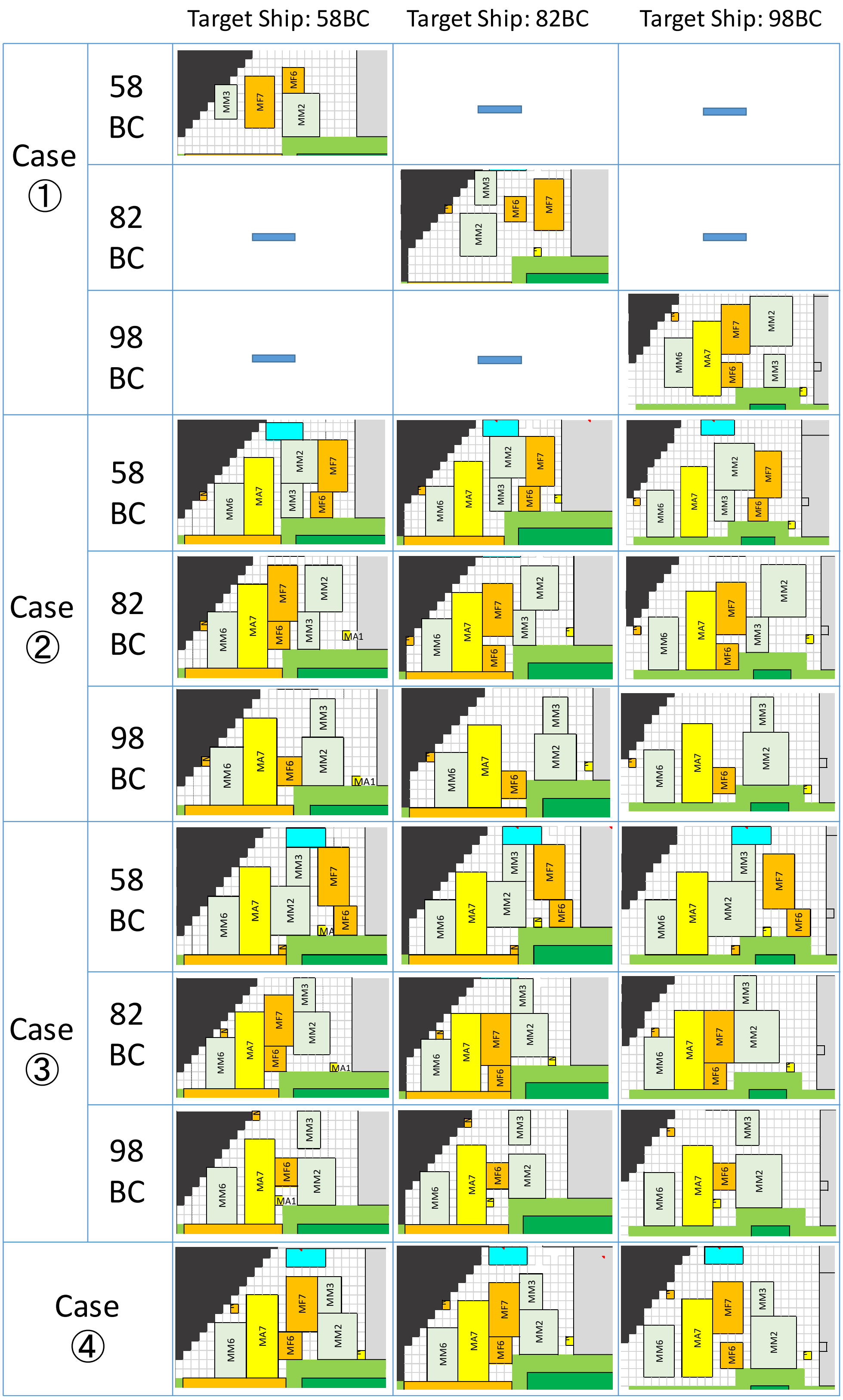


Fig. 6.3 Evaluation of arrangement in the different target ship

Each arrangement plan comprises of three different series ships: 58BC series, 82BC series and 98BC series respectively. Furthermore, each arrangement is implemented ion the different target ship and then will be evaluated the objective function. For the example, 58BC arrangement in case 2, will be evaluated the objective value using the 82BC and 98BC target ship. According to the Figure 6.3 above, the best result for case 2 and case 3 is arrangement of 82BC series. Furthermore, The arrangement of 82BC series in case 3 is close similar with arrangement result of case 4. The objective value of 82BC series is better than 58BC and 98BC series in all target ships. Therefore, the robustness of 82BC series is better than 58BC and 98BC arrangement result.

Table 6.5 Objective of all arrangement plans in all target ships

Objective Value		**Target Ship**		
		58BC	**82BC**	**98BC**
Case ①	Opt Arrangement of 58BC	100	-	-
	Opt Arrangement of 82BC	-	100	-
	Opt Arrangement of 98BC	-	-	100
Case ②	Opt Arrangement of 58BC	97.77	98.63	98.92
	Opt Arrangement of 82BC	98.52	97.25	98.82
	Opt Arrangement of 98BC	98.83	98.75	98.33
Case ③	Opt Arrangement of 58BC	97.94	98.83	99.15
	Opt Arrangement of 82BC	98.73	97.63	99.03
	Opt Arrangement of 98BC	99.17	98.86	98.55
Case ④		98.15	97.87	98.77

The characteristic of arrangement result of case 2 and case 4 in all target ships is depicted in the table 6.5 above. Based on this table, for the example, in case 3 the best result of 58BC, 82BC and 98BC series is highlighted with red color; 97.94; 97.63 and

98.55. Furthermore, each arrangement is implemented in the all target ships. The next step is recalculate the objective of each arrangement. Based on the table 6.5 above, the objective of 82BC series is better than 58BC and 98BC when implemented in the different target ship. Based on this explanation, it can be conclude that the 82BC result is good robust. The objective of 58BC and 98BC is big change when implemented in the different target ship. However, in the 82BC the objective change is small. Moreover, the improvement of arrangement of 82BC series will be adopted in the different module size and different mesh size. Finally, the 82BC series arrangement has the best robustness.

Chapter 7

Conclusions and Future Tasks

7.1 Conclusions

This study presents a new piping system arrangement with respect to series of ships in line with the modularization concept. Thus, the design and layout of the piping arrangement were first divided into two stages—module definition and module arrangement. Modularization involves the grouping of parts with strong dependency into a single group. In the previous research, modularization in piping design is implemented for each ship. Therefore, the modularization process is repeated due to the design of new ship type. However, based on the modularization concept developed in the automobile industry, the modularization is changing. The modularization concept is being employed in relation to the overall optimization of vehicles in the automobile industry. Consider the example of Nissan Motors' Common Module Family, which is a modular architecture concept that can be applied to a variety of different vehicles. As such, it enables the efficient design and manufacture of models such as small cars, sedans, and SUVs, simply by altering the combination of engine compartment, cockpit, and front and rear underbodies as modular units. The adoption of this type of approach to modularization provides an opportunity to enhance the design of engine rooms in shipbuilding. The DSM method was adopted in order to define an effective module that offers commonality of usage across different ships. The commonality modularization is required in order to consider the target ship of this dissertation. Various series ships with different size are conducted in this study.

The next important stage of this study is create the optimized module arrangement. In the piping design, module arrangement design of the part in engine room deals with the selection of the most appropriate and effective arrangements that will allow a greater working efficiency. Developing module arrangement is an important step because of the impact of the layout on the operation, repair, and maintenance. Because of the complex and precise nature of the module arrangement layout, the optimization procedures such heuristic, neural network, genetic algorithm is needed. Furthermore, an optimization system was developed to determine the module arrangement using a genetic algorithm in order to obtain exceptionally similar module-arrangement patterns for ships belonging to various series types, with specific consideration given to piping cost and similarity.

Conclusions of this dissertation are summarized as follows:

(1) Modularization is an effective method for reducing the complexity of piping design in the engine rooms of ships.

(2) In considering various types of series ships, a common modularization was obtained for both common parts and optional parts. In this study, generally, each ship in each series comprise of common piping system. Each piping system comprise of several parts. In this case, all ships consists of same common part. However, according to the different requirements from the owner, certain ship is equipped with additional part. Therefore, additional part (optional part) should be modularized separately.

(3) Using the commonality modularization concept, the new piping system can be generated by make the combination of common module and optional module. New piping system configuration is possible option based on the requirement from the owner.

(4) In order to achieve the optimization of module arrangement, the optimization system is formulated in consideration of various series ships.

(5) A genetic algorithm was used to optimize the module arrangement design. In this case, the objective function comprise of two important points; pipe cost minimization and similarity arrangement. In the other hand, adoption rate is important point to be

considered in order to make the weight factor of common module connection and optional module connection.

(6) Cost reduction is obtained using the optimization method. Optimized arrangement is better than current arrangement in the company for all series ships. In the case of design cost, the reduction is about 2%. However, in case of including the total cost (design cost and construction cost), the cost reduction is about 10% for various series ships.

(7) Modularization result and arrangement result are evaluated the effectiveness using the requirements and the past data from the company. Both modularization and arrangement are comply with all requirements.

(8) Use of the proposed method results in the attainment of a similar arrangement design for ships belonging to various series types. A similar arrangement has benefit in terms of maintenance and the design or production lead-time.

(9) Finally, based on this result, Tsuneishi shipyard decided to apply this concept to design piping system arrangement in the actual ship.

7.2 Future Tasks

The piping design system in the engine room is divided in to three steps, that is, piping diagram, part arrangement and pipe routing. In this dissertation, the two stage of piping design system are optimized using the modularization concept and the module arrangement. However, the pipe routing is not considered in this research. The pipe routing is the next important to full fill the holistic design of piping system in the engine room.

Following future works can be adopted to complement this study.

(1) The target ship of this study is bulk carrier with various series. It is big challenge to adopt this method in order to design in other ship type.
(2) In the modularization using DSM, the connection s between components represents only by structure model. In this case, the interface connection is pipe connection. However, the functional model such as flow object (signals, energy transfer, etc.) is not considered. In the future study, the functional flow is important to considered.
(3) In order to optimized the arrangement, genetic algorithm is used in this study. It is required for the future study to compare with other optimization method.
(4) In this study, the pipe length calculation is obtained using the vertical and horizontal calculation between modules. In the next study, the optimization of pipe routing is important to be considered. By considering pipe routing, the actual pipe length might be changed.
(5) The construction cost such as cost for pipe supporting and some additional material is not considered in this study. For the next research, it is require to include the additional cost.
(6) In this study, the modularization and arrangement are proceed in the two dimensional version. For the better result, in the future, using the three dimensional concept might be required.

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