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Value Based Development of Marine Engine Auxiliary Equipment

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Thesis abstract

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Marine engine auxiliary equipment is often neglected in terms of component selection and process control. Auxiliary equipment is often bundled together as a partly completed machinery. This kind of pieces of machinery are known in the industry as modules. Companies selling auxiliary equipment modules try to make modules that will suit as many engine makers as possible. This leads to failures of components and malfunctioning engines and can result in catastrophes, such as explosions, fire or environmental hazards in marine business where thousands of people are on board. A yard building a ship might not have the kind of focus that is needed to ensure proper engine operation when selecting components and systems, because they are building a ship where marine engine auxiliary components are only a fraction of the complete ship's construction. The bigger the engine the more engine components there are, which are not installed on the engine, such as coolers, valves and pumps. Marine engines are built to last for decades, therefore, it is very important to choose the right components at once to ensure their proper operation for years to come.

This thesis studied value based development to ensure all the points important to customers, both the yard building a ship and the cruise ship companies, are considered when developing marine engine auxiliary equipment. The marine engine auxiliary equipment modules developed during this thesis are a part of Wärtsilä's Engine Technology Research and Development project of the new Marine & Power plant engine program. The modules are limited to only one business area, Cruise. The value adding features of auxiliary modules of these two customers, yard and shipping company will differ, but in order to sell special auxiliary equipment modules the value adding features and functions have to be fulfilled for both customers.

Constructive research was used in this thesis and it was supported with theoretical studies on value based development. This study concentrated on large process systems which are used in ships or power plants. It is difficult to identify the value for a customer during the development of these complex systems. One way to identify the customer value during development is to develop systems with function based parts. Especially if there are several systems or a large portfolio. This way the added customer value can be recognized at an early phase and the reuse of components in some other part of the system can be utilized.

Keywords: Value based development, value based selling, R&D, marine, auxiliary equipment, shipyard, cruise business, modular portfolio

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Prosessinohjaus ja komponenttien valinta on kriittinen osa-alue merimoottorin apulaitteiden toiminnassa. Tämä osa-alue ei aina saa tarvittavaa huomioita, koska näiden laitteiden valmistajat tekevät valmiita koneikkoja, jotka sopivat mahdollisimman monelle moottorivalmistajalle. Tämä voi johtaa vääriin komponenttivalintoihin, tai prosessin väärään ohjaukseen, mikä voi pahimmassa tapauksessa johtaa katastrofeihin, kuten räjähdyksiin tai ympäristöongelmiin meriliiketoiminnassa, jossa mukana voi olla tuhansia ihmisiä. Telakalla, joka rakentaa laivaa, ei välttämättä ole tarvittavaa tarkkuutta komponenttien valintaan ja systeemin ohjaukseen, kun rakennettavana on valtava laiva, jonka moottorin apulaitteet ovat vain hyvin pieni osa kokonaisuutta. Mitä isompi merimoottori on, sitä vähemmän tarvittavia apulaitteiden komponentteja on asennettu moottorin päälle. Tarvittavia apulaitteita asennetaan moottorin läheisyyteen, mutta ne eivät ole osa moottoritoimitusta. Merimoottorit rakennetaan vuosikymmeniksi, minkä johdosta on hyvin tärkeää valita kerralla oikeat komponentit ja ohjata niitä oikein, jotta järjestelmä toimii tulevat vuosikymmenet.

Tämä työ sisältää asiakkaan näkökulmasta arvotarkastelua, jotta voidaan varmistaa, että molempien sekä telakan, että loppuasiakkaan vaatimukset on otettu huomioon merimoottorin apulaitteiden kehityksessä. Merimoottorien apulaitteista tehdyt koneikot, joita on kehitetty tämän työn aikana ovat osa Wärtsilän uuden meri- ja voimalaitosmoottoriportfolion kehitysprojektia. Koneikot on rajattu yhteen asiakassegmenttiin, risteilijöihin. Molempien asiakkaiden, telakan ja loppuasiakkaan, tarpeet ovat erilaiset, mutta molempien kannalta arvoa lisäävät toiminnot täytyy ottaa huomioon.

Työssä käytettiin konstruktiivista tutkimusta, jota tuettiin teorialla arvoperusteisesta kehityksestä. Tutkimus keskittyi suuriin järjestelmiin, joita käytetään isoissa voimalaitoksissa ja laivoissa. Näiden arvoperusteinen kehitys on hankalaa, koska arvoa lisäävät toiminnot saattavat jäädä huomioimatta. Tulokset viittaavat vahvasti siihen, että kehitys pitäisi järjestää funktioperusteiseksi varsinkin, jos tuoteportfolio on laaja tai monimutkaisia järjestelmiä on useita. Funktioperusteinen järjestelmä mahdollistaa asiakkaalle arvoa lisäävien funktioiden huomaamisen, sekä samojen komponenttien uudelleen käytön järjestelmän eri osissa.

Avainsanat: arvoperusteinen kehitys, arvoperusteinen myynti, tutkimus ja kehitys, risteilijät, telakka, modulaarinen portfolio

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Abbreviations and definitions

BMW	Bayerische Motoren Werke AG
CBM	Condition Based Maintenance
DFA	Design for Assembly
DFMA	Design for Manufacturing and Assembly
EAM	Engine Auxiliary Module, a unit connected to an engine
EEQ	Engineering and Equipment delivery
IACS	International Association of Classification Societies
LSCEC	Large Scale Engineered Systems
MDO	Multidisciplinary Design Optimization
OD	Organization Design
PED	Pressure Equipment Directive
RCCL	Royal Caribbean Cruises Ltd.
TERPS	Total, Engine, Room Packages for Auxiliary Systems
VDD	Value-driven design
W20	Wärtsilä 20 engine
W46	Wärtsilä 46 engine
W50SG	Wärtsilä 50 engine, SG, Spark ignited Gas engine
W32/34DF	Wärtsilä 32/34 engine, DF, Dual Fuel
WECS	Wärtsilä Engine Control System

1 INTRODUCTION

This thesis started at Wärtsilä Engine Technology Research and Development department. Engine Technology Research in Wärtsilä is done mainly in projects by two ways: New product development and Technology Development. Project organization consists of small, medium and large bore engine specific teams which are mainly focusing on new product development. Technology Development consists more of research projects which are then utilized together in new or existing engine platforms. Project teams form Research and Development teams which utilize the expertise of a line organization. The line organizations in Wärtsilä Research and Development consist of specific expertise areas such as Design, Analyse & Expertise department. There are also many other teams which are not part of this thesis. The design team is responsible for design and product management with the help of the expertise teams. The Analyse team consists of experts specialized in analysing and simulating the engine against vibration etc. The role of the Expertise department is to ensure proper quality, technology and operation. The Expertise department is formed of several smaller teams, such as: Engine Structure & Power Systems, Running Gear, Cylinder Head & Valve Mechanism, Materials & Tribology, Turbocharging, Ancillary Systems, Gas Systems and Fuel Systems. (Wärtsilä 2017.) The focus in this thesis is more on the Ancillary Systems' speciality area and other teams are not studied. The role of the Ancillary Systems team is to select, simulate, research and develop engine Ancillary Systems for marine and power plant applications. One part of the role is also to ensure that the engines in production are cost efficient, reliable and have the right technology through the lifespan of an engine. These system teams are also in charge of the technical support to service, production and laboratory.

Ancillary Systems consist of low pressure fuel-, oil-, cooling water- and pneumatic systems. As these systems are large, all the components are not installed on the engine. The components which are not installed on the engine can be installed in a ready-made machinery, often called as a module, to help in the assembly and to speed up the construction time. (Wärtsilä 2016.)

Wärtsilä is split into three business lines: Services, Energy Solutions and Marine Solutions. Engine Technology is a part of Marine Solutions' business line. Wärtsilä's purpose is to enable sustainable societies with smart technology and to be a total solution provider. (Wärtsilä annual report 2017.)

1.1 Objective of the thesis

The thesis was written to customers, the sales units in Wärtsilä and different technology departments working in marine and Energy Solutions' business line to open their eyes more for cooperation and the larger scope of supply to marine customers. With the larger scope of supply Wärtsilä can increase system integration, have added digital integration, increase safety and speed up commissioning. All these actions create more value for both Wärtsilä and potential customers. All the previously written objectives are highlighted in Wärtsilä corporate strategy.

The research questions this thesis is seeking answers for are:

- How to utilize the expertise gained in Energy Solutions business on Auxiliary module design and construction?
- There are already marine auxiliary module suppliers. What is the added customer value of buying the auxiliary module from the engine manufacturer?
- How to understand the needs of two different customers from shipyard to an end customer, for example a shipping company or a cruise shipping company?
- How to make a modular product portfolio?
- How to capture customer value in product development?

1.2 Limitations

This thesis focuses on the key areas of Auxiliary Systems and their development with added customer value. Auxiliary System in this thesis is limited to the main functional systems and its components that are mandatory for a medium speed 4-

stroke engine and which are not installed in the engine. The cruise business customer segment was selected because that is where the engine rooms are biggest. Even if the focus is only on one customer segment, the guidelines and methodologies discussed in this thesis can be kept similar to other segments as well. Standardized modules can then be installed more easily than in a small ship where most components are already in the engine and the auxiliary components are simple valves, heat exchangers or pumps that are installed where ever there is space. During the thesis, one set of marine auxiliary modules was developed for a new marine 4-stroke engine to prove the concept. The concept was then discussed in detail with a possible customer which is a shipyard building a ship for a cruise shipping company. New marine auxiliary modules were designed in detail but selling and the installation of the modules are left out of this thesis. Due to the sensitivity of the new construction, this thesis covers only the concept level rendered sketches without details on the components, process or control of the new auxiliary modules.

1.3 Progress of the thesis

This thesis is progressing from theoretical background to practical execution. The first part is the introduction. The second part involves the theory of product development, modular product portfolio, value driven development and value driven management. The third part is about ship building and shipping companies' operation and the fourth part is about the Wärtsilä systems needed in the auxiliary equipment. The fifth and the sixth part are about the value Wärtsilä can offer to the end customer and how that can be developed further. The final parts from seven to nine are about the results of this study. The theoretical background should be used as backup material when thinking about the results and the next steps mentioned in this thesis.

During the thesis a new large bore 4-stroke engine was developed for Wärtsilä portfolio. This engine will be targeted to marine and land based power plant applications, but the focus in this context is marine business and specifically cruise ships. Simultaneous development of an engine and auxiliary modules is very good, but the workload for the engine ancillary system team was very high. Wärtsilä has a specific Marine Solutions department in charge of marine auxiliary equipment, so the idea of making the first marine auxiliary module at the engine technology department was to help the Marine Solutions department to start developing a full portfolio of marine auxiliary modules instead of component supply. The Marine Solutions departments working with auxiliary equipment had already done some marine auxiliary modules in the past, but they were not so frequently selling those.

The progress of this thesis began from a new large bore engine development. There was seen a great benefit of having an own design auxiliary module to fully control the complete system linked to the engine. The first initial meeting with one of the world's biggest cruise company Royal Caribbean Cruise Ltd. (RCCL) happened early in the year 2018. During that meeting it was clear that Wärtsilä should develop own auxiliary module to fully support the functions of new engine type to be developed. The second meeting was on 12 April in 2018 at Mayer Turku shipyard with RCCL and Turku shipyard who is building the first possible new engine with the new marine auxiliary module developed by Wärtsilä. The participants from Wärtsilä in that meeting were Jaakko Koivula, a Senior Engine Expert in Ancillary Systems; Ilari Hyöty, an Engine Expert in Ancillary Systems; Mathias Björklund, the Manager of Ancillary Systems and Petri Aaltonen, a Program Manager of Large Bore Engine Development. From RCCL there was Harri Salama, the Technical Manager at RCCL and from Meyer Turku Shipyard there were Ari Rakkola, a Senior Marine Engineer and Juho Karppinen a System Engineer. During the meeting it became even clearer that the end customer RCCL was keen on getting the Wärtsilä designed marine auxiliary module on their new ships, due to the added value it provided. The Shipyard building the ship was not against this, but did not have much to comment on the modules because the module is only a very small part of the complete ship. After the meeting in April, Wärtsilä received the AutoCAD drawings of the ship to see the available space on that ship where to fit the possible new auxiliary modules. Due to a change of position inside Wärtsilä, concerning the thesis writer, further meetings are not discussed in this paper. After the requirements on space, functionalities and other technical details were clarified, Wärtsilä Ancillary Systems team continued the concept study with a 3rd party engineering company. Some preliminary results of that concept work can be seen in the conclusions part of this thesis. The requirements for the auxiliary module consisted of the customers' requirements, both the shipyard and the end customer, the engine requirements and the system requirements. Those requirements are not discussed in detail due to their sensitivity. On top of the previously mentioned requirements, there are marine specific equipment rules and regulations and the existing power plant auxiliary modules which were compared with the idea of utilizing the existing know how gained already form power plant applications.

After the initial input to make own design for the marine auxiliary equipment module the idea was brainstormed in several forums from sales departments, Marine Solutions' technical departments to engine technology departments. Positive feedback lead to more detailed studies on the background to see what should be included in the module to capture the added values of both the stakeholders, shipyard and cruise shipping company. Theoretical studies were made to understand the business profile of these two different customers. Detailed technical analyses were made on the power plant modules and those were compared with the rules and regulations of the marine cruise business. This led to some component changes and eventually to the rendered sketches that can be seen in the new marine auxiliary module section of this thesis. Those sketches were used for brainstorming with the yard and shipping company on the potential benefits of the new way of working if Wärtsilä would supply the auxiliary module with the engine. The results of that brainstorming can be seen in the conclusions part of this thesis.

1.4 Research methods used

The research methods used in this thesis were constructive, qualitative and quantitative. Constructive method starts by building a model of the current state by showing problems or improvement need, but there can also be a need for innovation. The needed improvements can also be that there are no innovations or the results of the innovations are not good enough. The second phase is the execution by showing the link between theory and practice and then the final stage is the target stage. Usually constructive research includes some new concept. The concept is not always related to a new product. It can be a new way to combine technical, human or information resources, or using them together. It can also be a new theoretical discovery. This kind of discovery has to be then reported in the conclusion part of the research. The end result is not always achieved as it was planned. It can go over, meaning that the results are even better than imagined. The results can also fall short and that can be expressed as a need for further research on the topic. Or sometimes there are no results, the research is left at the planning state. If the end result is still at the planning state, usually the result is so clear that conclusions can be made based on the results anyway. The difference between alternative research methods, such as theoretical, experimental or grounded theory methods are that they explain more about the current state and not how it should be. (Järvinen and Järvinen 2004.)

Järvinen and Järvinen (2004) divide the constructive research into five processes which are: Specification, Implementation, Procurement of parts, Parallel specifications and Implementation and Innovation evaluation. During the specification process the main task is the target state description. The implementation process is then a way to achieve the target state. Usually constructive research involves parts that need to be manufactured or procured and because there is no need to start to make again something that is already available, this is then done during the procurement process. Usually innovations are complex processes, so they need to be developed by parallel specifications and implementation process which are needed since it’s difficult to imagine something that does not exist. Parallel specifications and implementation often involves sketches and scenarios of possible solutions. The last process is the evaluation of innovations. During this process the researcher has to show the results of innovation concretely and estimate the possible side effects. (Järvinen and Järvinen 2004.)

Qualitative and quantitative methods were also used to evaluate the importance of different aspects. The qualitative method was more dominant since it is charactered as a full information research and from real cases. It also includes quite a narrow scope with a specific customer segment and interviews only a small fraction of the potential customers. The main research strategy used was the case study. The customer segment was specifically selected in order to proceed quickly to the desired direction. Typical case studies include a specific event, customer or customer segment. It can also include a process that is of interest, a single event at its natural surroundings. During a case study research information is gathered from several sources and by using many different methods with the main purpose in mind to show a typical behaviour. (Hirsjärvi 2009.)

2 THEORETICAL BACKGROUND

Following chapters concentrate on value identification and management during product development. There are also brief guidelines on how to develop large complicated systems which involve several systems or a large portfolio of products where value capturing is difficult to identify. At the end of the Chapter 2, there is brief introduction on value based selling and value based pricing.

2.1 Product development theory

Product development is a set of activities lead by a market opportunity that ends up in the production, sales and delivery of the product. Successful product development will end up in a product that can be produced and sold profitably. Profitability can be difficult to assess, so the following five product performance characteristics can be specified. (Ulrich 2012.)

1. **Quality** is as good as the customer thinks. Quality is reflected in the price and market share.
2. **Product cost** should take into account also the cost of manufacturing as well as tooling, capital investments and the incremental cost of producing each unit of the production.
3. **Development time** expresses how quickly a new product is introduced.
4. **Development cost** defines how much is spent when developing a new product. Usually a significant part of investments is required to achieve profits.
5. **Development capability** means how the company can develop new products, how big a team is needed and how effectively new products can be can be developed. (Ulrich 2012.)

If all these performance characters are good, usually the product is profitable. There are other factors to consider as well which might not necessary reflect on the profitability of the product. These factors can be the amount of jobs created by the product or production, high safety standards needed or by environmental aspect of how much waste the product or manufacturing the product will create. (Ulrich 2012.)

Product development can be split into six different segments. These are planning, concept development, system-level design, detail design, testing and refinement and production ramp-up. Before moving to the next phase an agreed checklist should be reviewed at end of every phase. (Ulrich 2012.)

1. **Planning:** Initial pre-study has to be made in order to get project approval. The output of the planning phase is a project mission statement, which specifies the project target market for the product, business goals, key assumptions, and constraints.
2. **Concept development**: Target market is identified, needs are defined, concepts generated and some concepts are selected for further development and testing. It is a description of the form, function and features of a product.
3. **System-level design:** System-level design is a definition of the product architecture, a description of the product info of its components and subsystems. It also includes a preliminary design of the key components and a preliminary plan for production and final assembly.
4. **Detail design:** Detail design is a complete specification of geometry, materials and tolerances. It includes a set of components designed or procured to make the end product.
5. **Testing and refinement:** In the testing and refinement phase the construction will happen with evaluation. Construction will be made of the actual production parts, but not necessarily in a similar way as the full production version. The finished product can then be tested internally or by the customer. After testing, final changes are done.
6. **Production ramp up:** Products are made at the planned production system. The main purpose is to see the errors in production and to train the personnel. Production ramp up can be done in phases in order to fix possible problems. (Ulrich 2012.)

Previously mentioned phases differ according to industry or product but these can be considered as general guideline on how the phases can be formed. In a large company or organization these are often specified already, which saves time on planning.

2.2 Controlling design variants

A whole power plant or a ship is a complicated engineered system were several subsystems are linked to each other with the purpose of controlling the system with the needed parameters. These systems have several variations depending on the application, customer or geographic requirements. This creates the need to control several design variants. When there are only a couple of variants, those can easily be controlled and maintained in a portfolio, but when the customer base is wide the need for controlling becomes even more evident.

One way to control design variants is to make a modular portfolio. A module is a set of standardized interfaces used to make a complicated system with a defined module building blocks. The complete set of modules can form a system and a set of modules can be defined as a platform. The platform will then form a product which can then be developed, marketed and produced efficiently. There are 4 main reasons to make a modular product portfolio. These are: a customer driven marketing strategy that leads to high product variance, reducing time to market, an existing platform product family and the need to have a close relationship between the product design and production. (Eriksson 1999.)

2.2.1 High product variance

The need to have customer focused solutions is increasing all the time and this leads to complex product portfolio. Complex product portfolio will eventually create more non-valued operations, and that will create a need to have systematic modular portfolio. Product portfolio of many companies has expanded to big portfolio. One example is BMW who had approximately 100 design variants in the 1980s and in 1985s had already over 500 design variants. This will create uncontrolled variants and spoils the possibilities in getting volume affects in production. Cost generated by product variants is also difficult to capture. In a large company several departments are working with a complex portfolio and that cost is difficult to calculate. Since the calculation of true cost of variation is difficult, people making decisions about product variants are unaware of the actual cost. (Eriksson 1999.)

2.2.2 Time to market

The need to get fast to the market has and will be decreasing all the time. For example cars previously had development time of 4-5 years and have now half of that time. First in the market is essential to keep the leading position in many companies. As an example of this from a high technology company was 6 months delay in product introduction resulted 33% less profit over 5 years while 50% development expense overrun resulted only in 4% less profit in 5 years. Product development projects are often difficult to plan because of desire to create too much new in one development project. This creates high risk of new technologies the company has no experience. Old products are also kept in the portfolio as long as possible until the product is no longer competitive. This leads to too big development projects when the other option would be to have continuous planned activity. (Eriksson 1999.)

2.2.3 Design scope

Design scope should be planned so that some parts of the design can be kept same, thus requiring only part of the full assortment to be designed new, while still getting new products to the market. Product properties should be assessed in details to understand what functions are the “order winners”. These functions in the product should be then carefully kept and developed in order to keep the orders coming. Product architecture is the base where different design variants should be made. If the architecture is made so that the variations are easily managed the product range can be very big. This creates the need to think about the full lifecycle of the product. (Eriksson 1999.)

2.2.4 Design and manufacturing

Majority of the design cost is determined already at design phase. Cost caused by poor design can be as high as 70-90%. Useful tools in overcoming high cost in production are i.e. Design for Manufacturing and Assembly (DFMA) and Design for Assembly (DFA). By utilizing these methods on a single product is not sufficient since it will create optimization on a single product variant but not for the full range of products that need to be manufactured. (Eriksson 1999.)

2.2.5 Modular product with module drivers

Modular product platform is a decomposition of product into building blocks with specified interface developed by the company strategy. Module is not the same as sub-assembly. Sub-assembly is result of assembly planning activity while a module is specific company strategy developed, chosen part of a product that takes into account assembly with standardized interfaces. Modules should be developed according to company strategy. For every module there should be a module driver that is the strategy of that specific module. These drivers will then be guiding the development activities of these modules. (Eriksson 1999.)

Ericsson (Eriksson 1999.) has selected 12 types of module drivers. These are carryover, technology evolution, planned product changes, different specification, styling, common unit, process or organization, separate testing, available from supplier, service and maintenance, upgrading, recycling.

1. **Carryover:** is a part of a subsystem that does not likely need any design changes between product generations.
2. **Technology evolution:** Parts that are likely to be changed by technology or changing customer demands.
3. **Planned product changes:** Parts that the company has a need to develop or change.
4. **Different specification:** Design of the product should be done so that the needed variation can be implemented to the product as late as possible

in the production. The need to have variation in the product should be then limited to as few product parts as possible.

5. **Styling:** Styling can be customer or market or brand driven. Usually parts that are most visible in a product.
6. **Common unit:** Part that is carrying the same functions for all the customers. Common units usually have large production volumes. Best situation is if common unit and carry over drivers can be combined.
7. **Process or organization:** Parts in production that require same production process are clustered together. For example parts that need welding should be together if possible, this way the welding can be automated if beneficial.
8. **Separate testing:** Some parts might require separate testing due to quality improvement needs.
9. **Available from supplier:** All the parts are not beneficial to manufacture in own production. Some parts can be then purchase from sub-contractors as ready modules. When deciding a module like this a make-buy analysis should be done.
10. **Service and maintenance:** Parts that need frequent service and maintenance may be clustered together.
11. **Upgrading:** According to customers preferences parts of the product can be upgraded. For example computer can be easily upgraded by changing some components.
12. **Recycling:** the need to have “green products” might be important for some customer segments. Easily recycled parts can be kept separate. (Eriksson 1999.)

Module driver terminology can be developed according to company’s preferences. The idea is to make a matrix of the whole modular product portfolio where the drivers can be seen. This way the planned resourcing, actions and needs from customers can be easily managed. Transparent product portfolio will then be helping on the information flow from development, production, purchasing and storage. (Eriksson 1999.)

2.3 Value driven design

In Wärtsilä Research and Development projects are almost always done in a multidisciplinary teams working on a specific area of expertise. The teams can also be geographically separated and this creates difficulties in leading the team and getting the right inputs for new product development. Diverse expertise areas are a great asset when experts can focus on specific area in every detail. This is needed in a high technology development projects that has the need to evolve all the time according to market, customer or technology needs. These geographically or multidisciplinary teams have the need to form virtual teams in order to proceed on the R&D project according to set targets by the stakeholders. This creates a need to form guidelines on product development process explained in previous chapter.

In a paper "Capturing organizational uncertainty in a value-based systems engineering framework" presented by Kwasa, Kannan & Bloebaum (2016) one way to deal with large scale engineered systems (LSCESs) such as ship or a Power Plant design is to adopt a value-driven design (VDD) to capture stakeholders preferences on value functions when using a Multidisciplinary design optimization (MDO) frameworks. That paper focuses specifically how uncertainty in organization structures affect the outcome of design of these large scale engineered systems. Systems can be considered large by the part numbers or by the way they are linked to bigger infrastructure such as a power plant is linked to national grid. To design these large scale systems there are hundreds of people involved from different organizations from the company doing the engineered systems to the end user. When using MDO in complex large engineered systems, smaller subsystems are needed to decompose to more manageable systems. MDO provides means to perform analyses on subsystems and the overall system when designing LSCESs. These frameworks help on getting objective functions on single or multiple performance objectives that are specific of the system. These systems are often linked to each other and the links have to be evaluated in order to make these sub-systems objectives more clear. By implementing organization design (OD) part of MDO value function formulation organizations are better formed to make new innovations by evaluating uncertainty in their organizations similar way uncertainty is evaluated in engineered systems with MDO. Value driven design (VDD) is a way to present stakeholder preferences in various aspects of system design in systems engineering. These preferences are captured in value functions when utilizing MDO which replace objective functions. Figure 1 express value driven design approach in complex systems engineering projects. (Kwasa et al. 2016.)

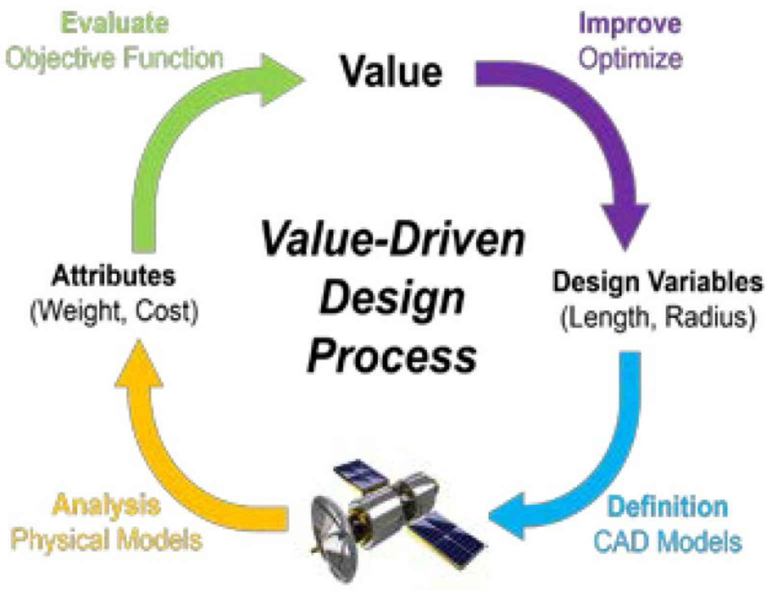


Figure 1. Model for value creation management (Kwasa et al. 2016).

The value function formulation requires decomposition of all the systems to fully capture the stakeholder value. By this way the subsystems added value can be truly captured. Large scale engineered systems are too big to be evaluated fully by their added stakeholder value, but if the systems are split into smaller, more manageable subsystems stakeholder value can be truly captured. (Kwasa et al. 2016.)

Organization design (OD) should not be forgotten either. By focusing on the structure of the organization designing large scale engineered systems, the teams and their way of working can be designed so that the stakeholder value is truly captured during product development projects. In organizations there are five distinct aspects that form the way of working. These aspects are: strategy, structure, reward system, human resource management and business processes. Organizations that develop systems that have tight physics based coupling tend to develop products that mirror the organization structures. Organizations use resources the most efficiently when organization and product structure is similar. (Kwasa et al. 2016.)

2.4 Lean Value based product development

Lean manufacturing has evolved for several decades but it's still quite rare in product development processes. Lean is focusing on value and trying to get rid of non-value added functions. In product development process a development need is well identified. It needs to be as lean as possible. Product development process should be faster and cheaper without sacrificing quality. In lean product development process waste elimination has been good way to reduce cost and create value. But unlike in manufacturing which deal mainly with tangible products and repeated sequences product development process is highly creative activity focusing on knowledge. In lean product development process which is value driven the focus should be on motivating designers, managers, suppliers and customers to create value for potential customers. In lean value based product development process the focus should be on how to increase identified stakeholder value. Research should be done to address the value creation actions and how to handle the value creation process leaner and stronger. Strong, lean, innovative and continuous development process can ensure value creation benefits to all stakeholders. (Tianyi 2011.)

Product value is generally defined by the end users and is meaningful when the product meets customers' needs at competitive cost, time and quality. Cost, time and quality of bringing a product to market are usually in conflict with each other. Each activity in product development process should be assessed by how much they create value, consume resources and produce stakeholder defined benefits. Some activities create value while others waste resources. These can be non-value added activities. These activities might help other activities to create value to a product and should not be removed without evaluating the effect. (Tianyi 2011.)

2.5 Creation of value management

Core value creation consists of several phases such as: Knowledge management, Motivation management, Risk management and Control. Creation of core value management is interaction of motivation management and knowledge management. It is influenced by customer, corporate and social principles. This interaction should focus on actions that affect product cost, quality and time to market without forgetting risk management. (Tianyi 2011.)

2.5.1 Knowledge management

Creation of new knowledge is the central theme of lean product development process from concept creation to launch. Value is created by in knowledge management by decision making, innovation and consensus building. Value in product development is in the form of product concepts and product realization documentation. Successful product development companies create “knowledge pull” from the employees of the company. Knowledge management is key element and core value of success factor for a company. (Tianyi 2011.)

2.5.2 Motivation management

To ensure lean and smooth value flow people must be motivated to value creation. Motivation is needed in all employees such as designers, engineers and managers who are involved in development process. They create value to the product. Motivation can be economical interest, social status, achievement, recognition, promotion or responsibility. This motivation pull creates value and efficiency in product development process. (Tianyi 2011.)

2.5.3 Risk managment

Risk management has to be done properly during a product development process since it’s a high risk process by technology, business innovation or new market opportunity. There is a difference in risk management from manufacturing and product development. In manufacturing risk is usually waste, but in product development it can have positive or negative affect on product development project. Risk reduction in product development project is a way to eliminate uncertainty and it means it creates information which can create value. Taking and controlling risks properly designers and engineers can seize opportunities of new technologies, new market places or new market needs by providing new products with specific value to customers. Some customers want to take risks and buy new products with uncertainty because of the high value and features in those products. Development teams should manage risks rather than reduce them. There should be an optimal balance between cost and value of carrying risks versus cost and value of mitigating risks and take risks based on company's strategy. (Tianyi 2011.)

2.5.4 Control

In lean product development process control means assessing, evaluating value, planning work, scheduling and allocating resources to maximize efficiency in value creation and reduction of waste. It also creates value by knowledge generation. Product development team should also apply centred control by setting standards for value creation, measuring performance, evaluating value, providing feedback and improving product development process. Stakeholder control of what is valuable can also increase flow of information and motivation management. Feedback improving efficiency and ensuring quality will also indicate non-value added processes which can then be eliminated. This will ensure value creation management actions and eliminate waste in lean product development processes. (Tianyi 2011.)

2.5.5 Core value creation management model

All the above phases work together as core value creation actions. The relationships between these phases are illustrated in Figure 2.

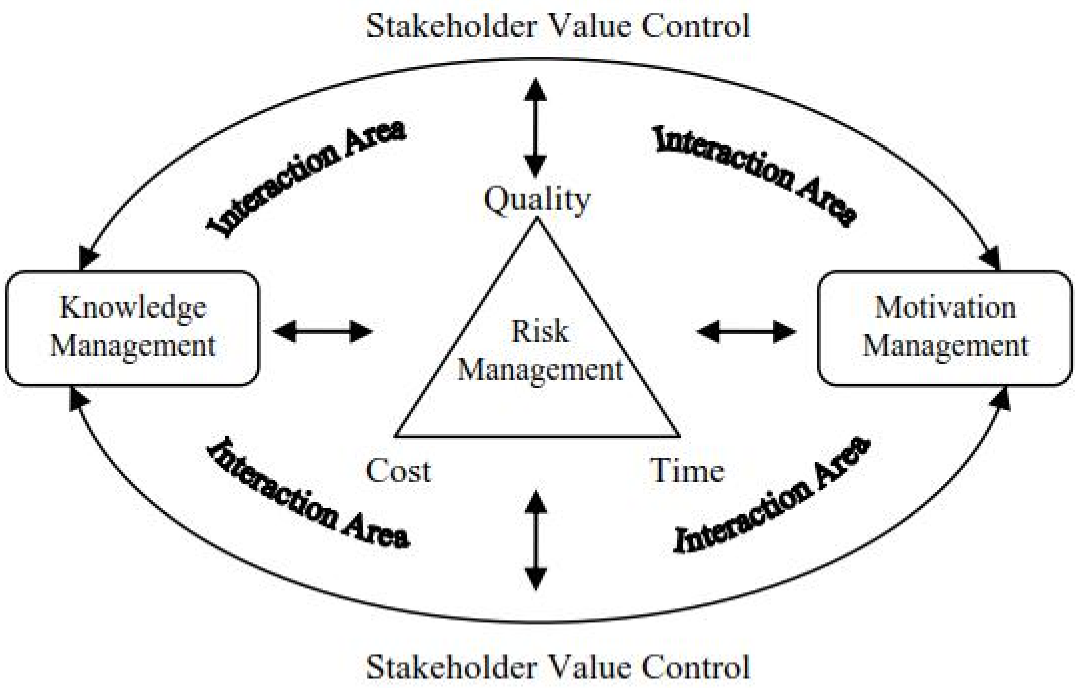


Figure 2. Model for value creation management (Tianyi 2011).

With this kind of management for company value and personal benefits all the teams working with product development processes will be motivated to create added value. Knowledge management enables team managers to perform planning, decision making, resource scheduling and provides valuable information of value control. Value creation circle is centred with fundamental value triangle of lower cost, higher quality and right time to market. Risk management is in the centre of triangle to balance innovation and failure. Inner circle sets the standard of quality, cost and time for the outer circle and outer circle provides feedback to inner circle to manage risk and update core value standards. (Tianyi 2011.)

Biggest challenges of any company doing systematic product development is the knowledge management and information of knowledge. Product development process should be as transparent as possible and product development should have defined process accessible to all the people in the company. Knowledge is not easy to acquire. It can be acquired by training, learning and doing but biggest problem is the information of the acquired knowledge. To give an example of a person who has been in the company for several decades. One good way to try to keep the knowledge is to make systematic documentation on what has been tested and learned. Design guides, engineering guides, expert guides, system guides etc. are also good way if done in a periodic manner and every time when new results have been found. This way the knowledge transfer is also kept in the company if some of the key persons leave the company.

2.6 Value based selling

In many different business areas suppliers find it difficult to convey the message of their products superiority to customers. Buyers are short on time, resources and results so the sellers need to provide tangible evidence of the value they can deliver to their customers. Value creation and value capture have become new selling argument but few companies really understand the value potential of their product offerings. Even few companies have the means to express the monetary value of their product offerings to potential customers. (Töytäri, Brashear, Parvinen, Ollila, Rosendahl, 2011.)

Key findings on value based selling research indicate the importance of customer focused approach including full understanding of customers business and conducting value analysis in close cooperation of the customer. Other key aspect is to have “open books” approach, reference cases and using value based pricing and diverse skill set from sales team. Value covered in management literature is considered to be subjective, customer focused, contextual, and evolving over time and subject to other alternatives. Desired value is what customer wants to have from a product or service offering in usage situation to achieve desired goals. Customer’s benefits thinking is useful when designing new offerings but incomplete if there is no mention of customer sacrifices coming from the purchase. Customer’s perceived value is the net value achieved considering all the benefits and sacrifices customer has to make in the search, purchase and use of the offering. Customer perceived value can be defined according to following Figure 3 as difference between customer’s desired value and customers total cost of ownership. (Töytäri et al. 2011.)

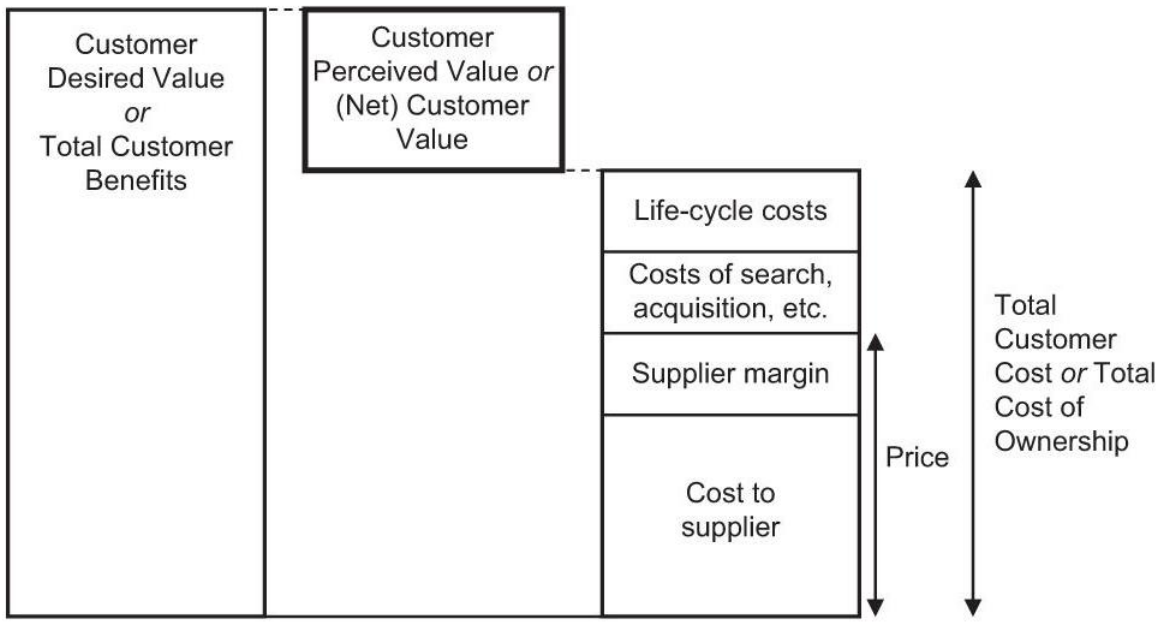


Figure 3. Customers desired value and perceived value (Töytäri et al. 2011).

Total cost of ownership plays the most important role in marine and energy solution business. Internal combustion engine power plant or ship and their ancillaries is built for several decades. Fuel consumption is usually the biggest influencing factor for a total cost of ownership. Second is the service. But these can differ depending on the customers and type of market they operate. Only by thinking these two factors product development should focus on efficiency and service needs. But this is not the only factor to be considered. In Wärtsilä the business model of service is evolving around original equipment spare part and global service network. Initial purchase cost of internal combustion engine and their ancillaries is minor compared to the full cost of ownership during the lifecycle of the equipment. This has to be then expressed by detailed case examples and references in order to convince potential customers. The needs from market have also changed rapidly in the land based power plants with more renewables such as wind and solar entering the market and shifting internal combustion power plants into peak load stabilizers when the wind is not blowing or sun shining instead of traditional base load power plants that run continuously.

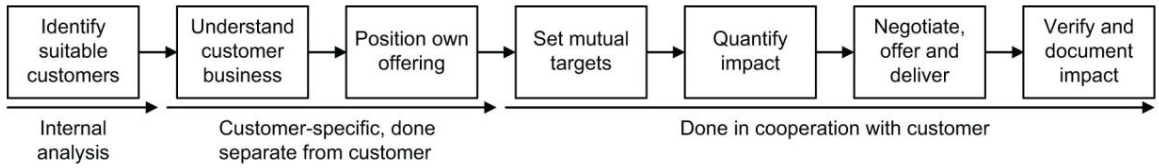


Figure 4. Process framework for value based selling (Töytäri et al. 2011).

In the paper "Bridging the theory to application gap in value-based selling" Pekka Töytäri and others created a suggested value based sales process that could very well be adapted to any industry. This process had eight stages which are shown in the Figure 4. These stages are, identification of customers, understanding their business, positioning own offering, setting mutual targets, quality impact, negotiation and offering, delivering and finally verify and document impact.

2.7 Value-based pricing

Pricing of a product can be done by three different approach. These approaches are cost-based, competition-based or value-based. Value-based pricing is done by the customer's eyes and not all customers see the value similarly. Value can be cheap price, quality, service or known supplier. Challenge with value based pricing is how to capture value so that it can be formed into value in the price and that the customer is willing to pay for that price. (Järvenpää, Länsiluoto, Partanen, Pellinen, 2013.)

Value based product pricing has been highlighted in a paper "Industrial product pricing: a value-based approach" written by Stephan M. Liozu and Andreas Hinterhuber. Paper concentrated on small and medium sized industrial firms in U.S so all the data cannot be reflected to large companies pricing. Every company also has different product portfolio and structure which should be taking into account during pricing. This paper presents five findings on pricing which are:

1. Companies using value based pricing rely on formal market research, scientific pricing methods and expert recommendations while those using cost or competition rely on experience
2. Companies that don't have pricing dedicated functions don't generally use value based pricing. Those who do, follow up on price data with key performance indicators and weekly reviews

3. Pricing responsibility function varies based on pricing orientation
4. Companies using value based pricing had centralized pricing functions to support pricing decisions
5. Companies using value based pricing had detail training on personnel working with pricing. Companies who used cost based had no training (Liozu & Hinterhuber 2012.)

Companies that focus on value based pricing had tools to support pricing decisions and that helps on removing intuition and gut feeling from the final price setting process. Top executives of those companies highlighted the importance it implement tools that help calculated total cost of ownership and value-in-use pricing methodologies. (Liozu & Hinterhuber 2012.)

The paper written by Liozu & Hinterhuber has limitations due to its narrow scope and the size of the companies and their business model. But even considering the limitations value based pricing should be kept in mind always when thinking new product prices.

3 SHIP CONSTRUCTION

Shipbuilding is a high risk business. Production process risks of new buildings can be grouped into three major parts: Work of design, Material procurement and production processes. Each stage will bring its own risks and accumulate overall risk. All these risks has to be managed with a proper risk management. There are excess capacity in the shipping world causing for example China to react by focusing on high productivity, efficiency, reduce cost and energy consumption. There are several reasons why shipbuilding industry should develop. It is the main industry for supporting industries. The development of ship building industry will help develop other industries and will create multiplier effect and help industrialize the whole country. (Basuki, Manfaat, Nugroho & Dinariyana 2012.)

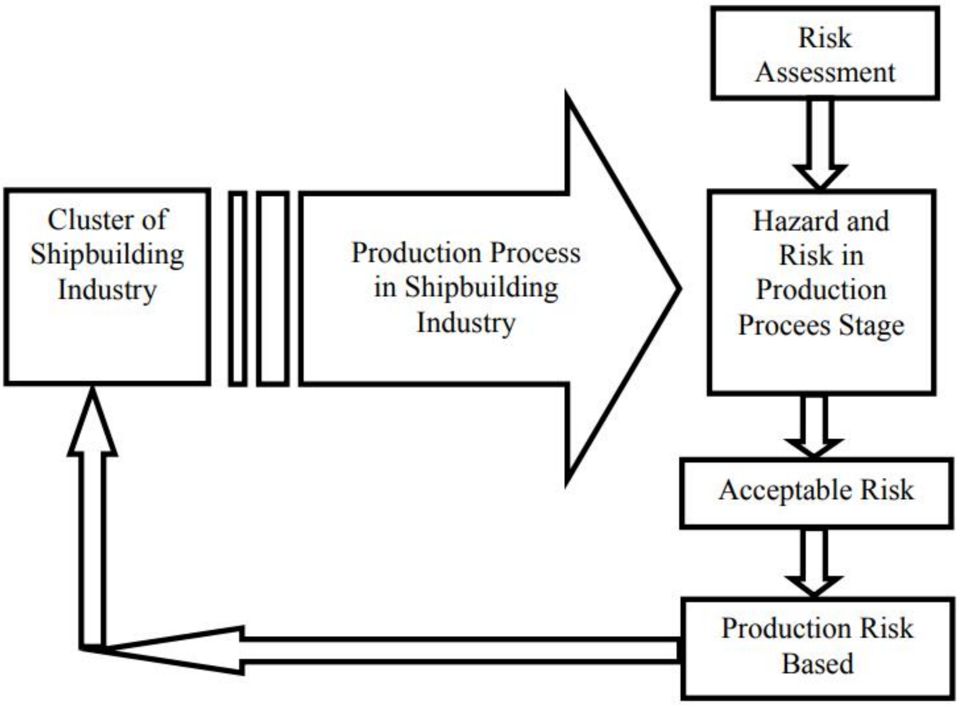


Figure 5. Production risk based concept (Basuki et al. 2012).

According Figure 5. It is clear that any risk in production and operation of a ship that will cost billions of euros to build and operate will have a high financial affect. Besides financial, the risk is also high in terms of safety and operation. Any prefabrication and testing of any equipment related to a high risk production such as ship building will then be necessary in order to minimize risks and maximise production efficiency.

3.1 Shipping

Shipping plays an important role on the growth of world economy. Transport of goods is increasing at much higher speed than the world economic growth. Over the years the goods have changed to smaller but often more valuable i.e. computers, mobile phones etc. The shipping industry has several different aspects to be considered. Interesting in this context is the cruise shipping as that needs significant differentiation which mean customer specific flexible shipbuilding. The following Figure 6 show some of the commonly known shipping segments and how in those segments the need to differentiate from the competitors is affected. Cruise ship are large which will be limiting the selection of shipyards. Cruise segment is also high tech industry which is also limiting the shipyards to places where that technology is easily available. The needed sub-supplier base has also been formed by earlier cruise orders which will create difficulties to enter to the market as a new company. Since the ships are huge in size usually only one ship can be made at a time which creates the need to build a ship as fast as possible. If the ship takes several years to build the needs from shipping companies can then lead to orders from several similar shipyards specialized in the cruise segment. (Wijnolst 2009.)

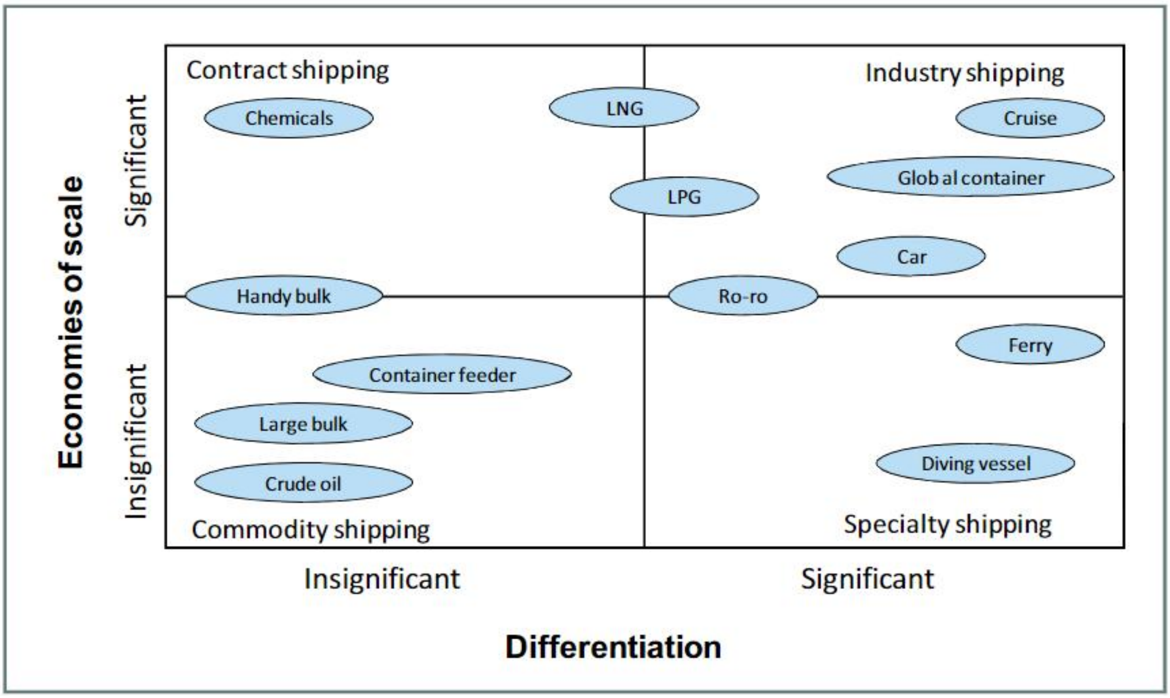


Figure 6. Examples of shipping segments as strategic types (Wijnolst 2009).

The need to differentiate creates the need to innovate. This will create pressure to the shipyard and ship-owner to continuously seek for new solutions that will create value to their customers. The cruise business is dominated by few very large cruise companies. These companies can be seen from the Table 1. The cruise ships in operation are average 19 years old and some of the cruise shipping companies have ships still in operation are in average over 50 years old. Top 3 cruise companies have ship fleets that are in average 11-14 years, which indicates that the best companies build new ships constantly. To keep having the lead the companies must build new all the time. (Wijnolst 2009.)

Table 1. Number of ships from the top cruise companies in 2008 (Wijnolst 2009).

Company	Number of ships	%	Lower berths	%
Carnival	97	27	175,641	45
RCL	41	11	84,319	22
Star	14	4	22,266	6
MSC	10	3	19,600	5
Apollo	12	3	14,915	4
Others	184	51	70,830	18
Total	**358**	**100**	**387,571**	**100**

Three nations dominate the cruise building segment. In 2008 they were Finland, Italy and France. They account for over 42 % of the total cruise fleet. For a cruise company to succeed following points can be noted:

- Building a bigger ship will create cost reductions in maintenance, inventory and in reduced hotel operations
- Differentiation by unique ship, innovative concepts and new destinations, diversity of brands
- Increase share of repeated customers
- Managing strategic investments, by contracting new vessels with respect to delivery date, for newbuilding's as well as blocking the yard capacity for competitors. (Wijnolst 2009.)

Ship is always made by order individually or as a series of ships that are alike. It is a high risk business where several different organizations need to interact in order to get to an agreement with proper funding. External funding is always needed due to the high costs and nature of the business.

3.2 Shipyard

Traditional way to build a ship was that shipyard did most of the construction by themselves, but the pressure to shorten lead times and the need to have a wider range of portfolio has lead the shipbuilding industry to move more project wise construction. This way the ship or even ships can be made simultaneously, overlapping or side by side. One good way to cut down lead time is to outsource parts or subassemblies that are not within the core business of the shipyard. Typical outsourcing topics are engineering and sub-constructions. Sub-contracting has always factors to be considered like the interfaces, deliveries and responsibilities. Malinen (1998) has found several interesting points in his doctoral thesis "To Buy, Sell, Exchange and Produce – A Case Study in the Shipbuilding Industry in Shipyard-Subcontractor Exchange" about subcontractors role in shipbuilding. Subcontractors' role has become even more mandatory since ships are becoming more complex and have more customer specific requirements. Industry has transformed so that parts of ship which are not core business should be outsourced, responsibilities from outsourced subassemblies have moved to subcontractors and industry has changed to managing projects with several subassemblies instead of traditional shipbuilding only at the shipyard. Shipyards are having less manpower and focus more on project management and buys even more turn-key deliveries. These can be for example restaurants. Interesting point from the thesis is that shipyard does not market themselves that they need subcontracting, they rely on market information and the needed sub suppliers will come to them. (Malinen 1998.)

3.3 Ship construction process

Before ship construction will begin there are extensive negotiations, agreements and meetings until the agreement has been signed between shipyard and ship owner. Unlike a car, ship is not made in prefabricated models. However the trend is nowadays that a ship is ordered as a series of ships in order to standardize and speed up construction and design. Advantages of a standardized ships is that customer knows what he will get, design is proven, design and engineering period is shorter and total cost will be lower since the design and engineering is split between several ships. By standardizing a ship there can be also disadvantages. Design might not be optimal for the shipping company and that they can influence only to limited amount of details only, competitors can operate similar ships and level of innovations can be lower. (Dokkum 2013.)

3.3.1 Shipping company's requirements

Most shipping companies will make a formal owners requirements if the ship is new and will be optimized for the shipping company's use. Formal agreement specifies the following topics:

- carrying capacity, service speed and trial speed
- types of cargo a ship must be able to carry
- cargo hold, hatches, and cargo gear
- the number of crew and passengers

- what kind of crew is needed, how much luxury and what kind of spaces are needed, dimensions and general accommodation
- operational range
- special requirements
- Final completion date
- Required certification, classification society and the flag of registration. (Dokkum 2013.)

Usually a shipping company will submit the formal requirements above to several shipyards to call for tenders. Then the shipyard will inform if they are interested in preparing the tender. Usually the most important aspects of the tender are experience in similar ships, capacity to make the ship, the amount of material and manpower, special interest, price and the expected completion date. After that the shipyard sets a date when the tenders have to be submitted and selects the preferred partner. Usually the shipyard already has a preferred partner and other shipyards' tenders are used for the negotiation. (Dokkum 2013.)

Auxiliary components are a very small part of a complete ship. The total cost of a new large cruise ship is in milliards of euros and the auxiliary modules are under one present of that, but they have a vital role in the ship's operation and safety. If a fuel or a cooling water pipe is broken, the engine cannot provide the needed power. Or if some component of the auxiliary system fails, the whole ship can lose its power. However, normally a cruise ship has extra engines and engines are arranged in order that some are main engines and some auxiliary engines for safety and reliability purposes.

3.3.2 Design and construction

Most shipyards have a project or design department where the preliminary designing and final calculations are done before the final design. During the design work, the shipping company can influence, for example, the engine room layout, or the auxiliary room. A standardized auxiliary room or a space in the engine room can be reserved to the engine auxiliary modules that are installed at the same time as the engines. For a large cruise ship it is easy to standardize the auxiliary room, but for a smaller tug boat, for example, there might not be extra space, so the needed auxiliary components have to be spread where ever they fit. Standardized modules are always better since they can be prefabricated, tested and inspected. This will save time in construction. Most probably the ship construction time is not limited because of auxiliary equipment installation and construction, but by having initially designed and tested modules there will be less issues to be solved and more attention can be paid to where it is needed. The shipyard is also in charge of commissioning and the sea trial together with the engine manufacturer. If the pre-manufactured auxiliary modules are proven by the engine maker beforehand, there will be less problems during the sea trial, or if the issues come, they can easily be addressed and fixed due to a well-known design.

3.4 Value

During the design work of a ship, shipping company can influence on the design of these auxiliary rooms. If the engine manufacturer is able to make a standardized pre-fabricated engine auxiliary modules these can be installed to the ship at the same time as engines. This way all the engineering hours that would normally go to engine auxiliaries are saved and the total construction period can be shorter. This would also increase quality since pre-fabricated modules can be tested separately and can be selected based on experiences. These pre-fabricated modules can also be developed specifically for a specific engine type to include the functionalities that the shipping company who will eventually operate the ship would value. For Wärtsilä this is great asset since the engine used in a power plant or a ship is very similar. Components can be tested in a harsh conditions with for example baseload power plant running continuously with bad quality heavy fuel oil. Biggest difference between auxiliary modules for marine and land based power plants are the needed certifications for components. In general land based power plants follow country specific rules and regulations and i.e. Pressure Equipment Directive (PED) but in marine the equipment has to follow specific classification society rules, which are controlled by IACS (International Association of Classification Societies).

The needed auxiliaries depend also from the engine. Usually the engine makers prepare documentation called product guide and installation manual to help shipyard to find the needed auxiliary equipment. These guides are extensive documentation that are done by the engine manufactures to guide on selecting the needed auxiliary equipment. The shipyard building a ship will have to read, discuss and procure all the needed equipment stated by the contract with the engine manufacturer. Procurement can be a split scope also, partly for shipyard and party for engine manufacturer. When the shipyard will read the documentation there is always a risk of misinterpretation. Shipyard has to understand all the detailed technical matters written in these documents. Solution for this is that the engine manufacturer would supply most of the important auxiliary components.

4 AUXILIARY SYSTEMS IN MARINE & POWER PLANT

Large 4-stroke engine cannot operate alone with only in the engine installed systems. There are always components and systems which cannot be installed in the engine. The larger the engine the more components are off the engine. The split between these two systems can be called Ancillary Systems = on engine and Auxiliary Systems = off engine.

4.1 General process description

In a Wärtsilä 4-stroke engine the combustion process requires several different systems. Main systems are fuel, lubrication oil, cooling water, starting air, gas systems and turbocharging system. Each engine model requires different set of pressure, flow & temperature range. These requirements are fulfilled with systems and components that are either installed in the engine or close to the engine in the ship or a power plant machinery.

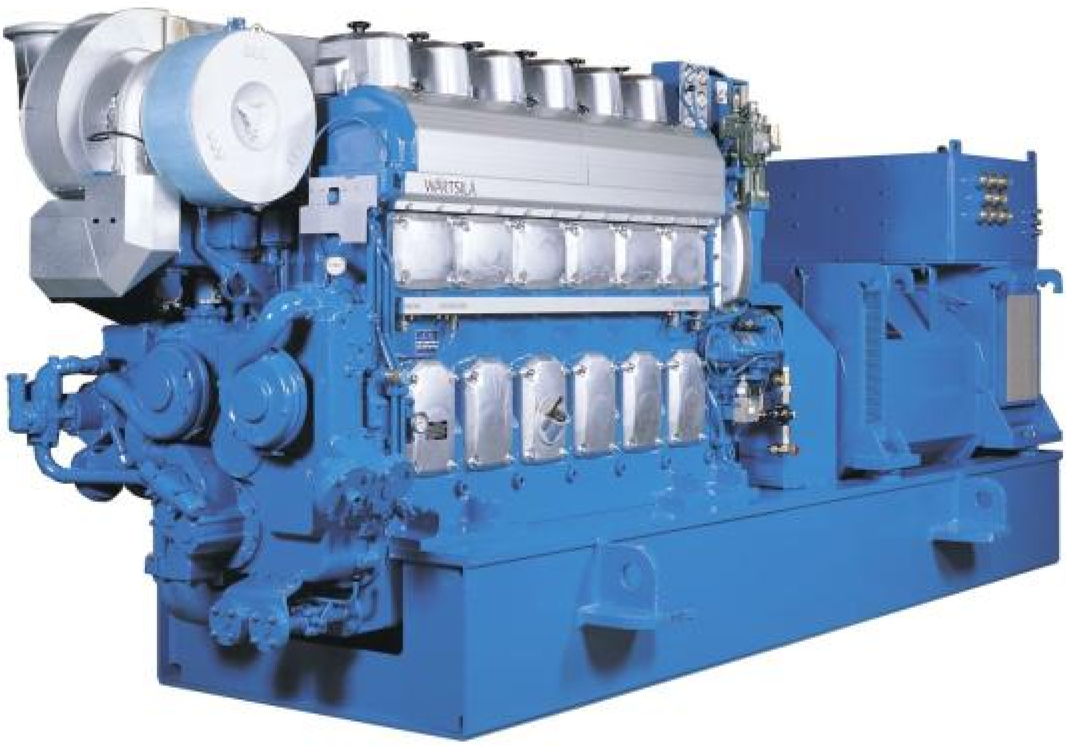
4.2 Ancillary Systems

Engine technology Ancillary Systems department is responsible for developing and maintaining engine components. These components are split into several systems as can be seen from the Table 2.

Table 2. On engine Ancillary Systems grouping (Wärtsilä 2016).

Ancillary Systems			
Low Pressure Fuel Oil System - Filters - LFO pump - Pressure control valves - Pressure accumulators and pulse dampers - Piping/channels - Sealings	**Lubricating oil system** - Pumps - Filters - Oil cooler - Thermostatic valves - VIC/VEC valve block - Pressure control valves - Built on separators - Piping/channels - Sealings	**Compressed air/Starting system** - Main starting valve - Starters - Solenoid valves - Pressure control valves - Filters - Stopping vessel - Piping/channels - Sealings	**Cooling water system** - Pumps - Thermostatic valves - Deaeration systems - Piping/channels - Sealings

Since all these systems continue outside engine in a ship or in a power plant the responsibility areas are sometimes difficult to decide. The whole system has to work properly in order for the engine to perform in the needed way.



Picture 1. Engine Genset W6L20 (Wärtsilä 2018).

Wärtsilä engines can be installed to a generator set which is a combination of an engine and electrical generator. These can be diesel fuelled, gas fuelled or heavy fuel fired engines. Some engines have generating sets that have a common base frame forming a single unit or an engine mounted on a separate frames as can be seen from Picture 1. There are several different designs available in Wärtsilä portfolio, those are not in details discussed in this thesis. In the following sections the most common systems are explained briefly. (Wärtsilä 2018.)

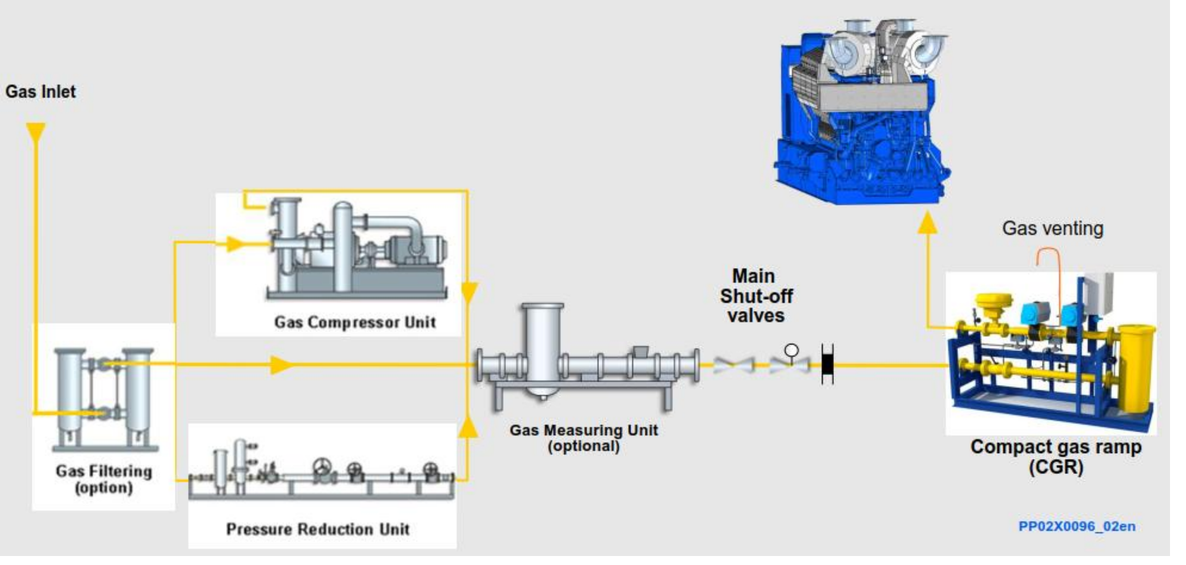
4.3 Auxiliary Systems

The reason to split the components on engine and off engine is very logical. Engine is prone to vibrations due to rotating forces and mass forces from the combustion process. This leads to the need to have very rigid components that will not vibrate and fail during the expected lifetime. Other important factor of on engine installed components is the available space and usually higher temperature of media and surrounding air or contact point. As a rule of thumb in Wärtsilä medium speed 4-stroke engines the smaller the engine is the more ancillaries are installed on engine. That is also very logical because the ancillary components needed for smaller 4-stroke engine are smaller and easier to install compared to a large 4-stoke medium speed engine. As an example a small W20 engine the only needed components that are off the engine are filters and pumps needed for fuel and pneumatic compressors. For a larger Wärtsilä engine W46 the needed components off the engine can also be related to the process, not only to the space, heat or vibration. W46 can have cooling water pumps that are installed in a module together with an oil filter, fuel filters, pumps for fuel etc.

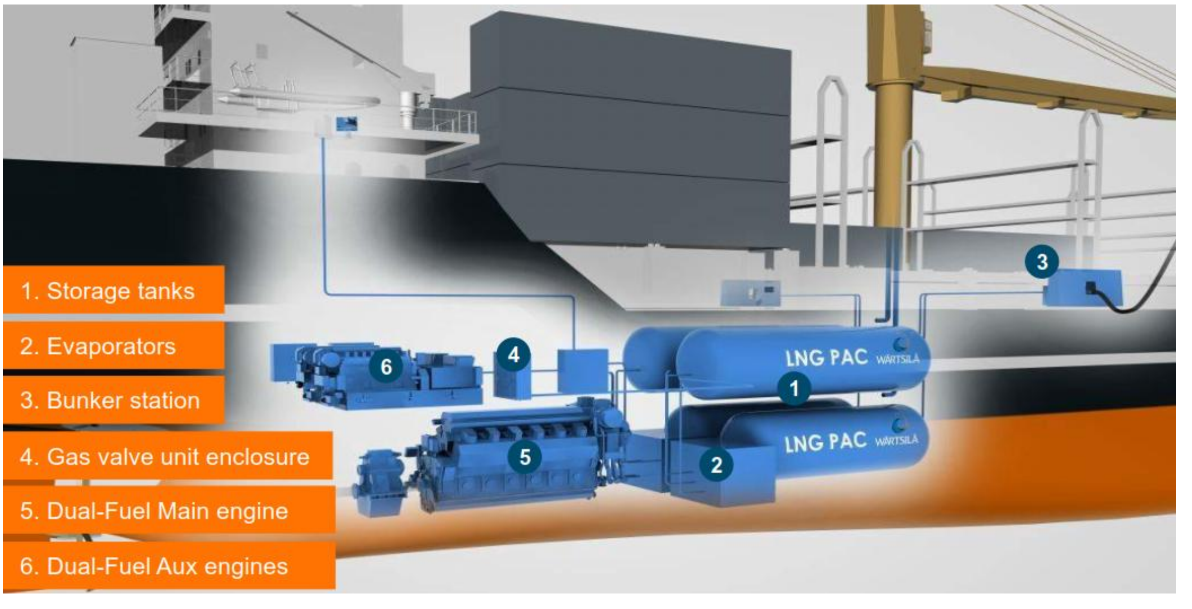
All the following systems consist of several components constructed into a total power plant or a ship. The needed components from these systems can be built into ready-made modules to help on construction, quality, and connectivity and are a vital part of the complete machinery.

4.3.1 Fuel gas systems

Fuel gas systems is split into several different sections. These sections can be made into modules in order to speed up assembly, construction, control and improve quality. The purpose of gas system is to feed the engine with reliable clean gas at correct flow and temperature. All Wärtsilä engines gas engines SG (Spark ignited Gas) and DF (Dual Fuel) are designed for continuous operation on gas. (Wärtsilä 2018)



Picture 2. Typical Power Plant gas system (Wärtsilä 2018).

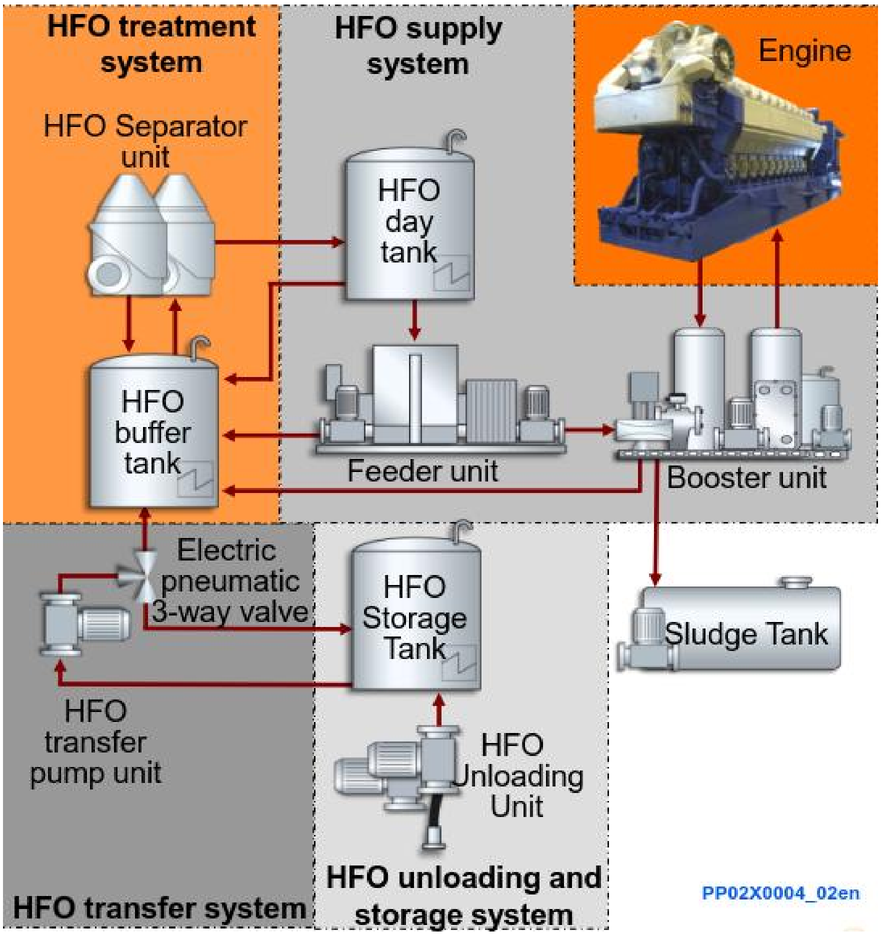


Picture 3. Wärtsilä LNGpack, marine application (Wärtsilä 2018).

The main system design philosophy of typical power plant gas system is presented in the picture 2 and a typical marine application gas system can be seen from picture 3. There are many different regulative authorities working on these systems. These regulative authorities form a guidelines on how to design and control of these systems. Marine and power plant systems are very similar, but the needed components, suppliers and construction is different. (Wärtsilä 2018.)

4.3.2 Fuel oil systems

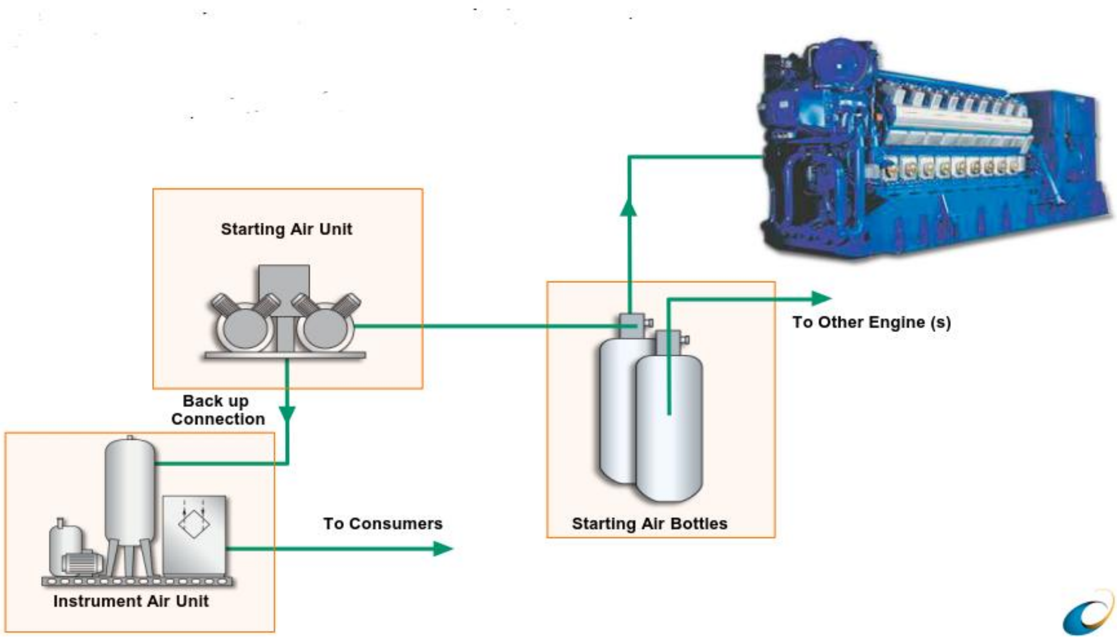
Fuel systems can be several different depending on the fuel quality, plant type and application type. The purpose of the fuel systems is to supply clean fuel with correct pressure and viscosity uninterruptedly. Typical fuels are light fuel oil (LFO) or heavy fuel oil (HFO) or both. Fuel system is split between engine and external systems. Internal system can be split to low pressure and high pressure systems while external system can be split to several sub systems such as unloading and storage, transfer, treatment and supply as can be seen from the following Picture 4. (Wärtsilä 2018.)



Picture 4. Typical fuel oil system on a Power Plant (Wärtsilä 2018).

4.3.3 Compressed air systems

Main purpose of compressed air system is to feed the engine with clean, dry air to control, safety devices and engine starting. Typical example of that can be seen from following Picture 5. (Wärtsilä 2018.)



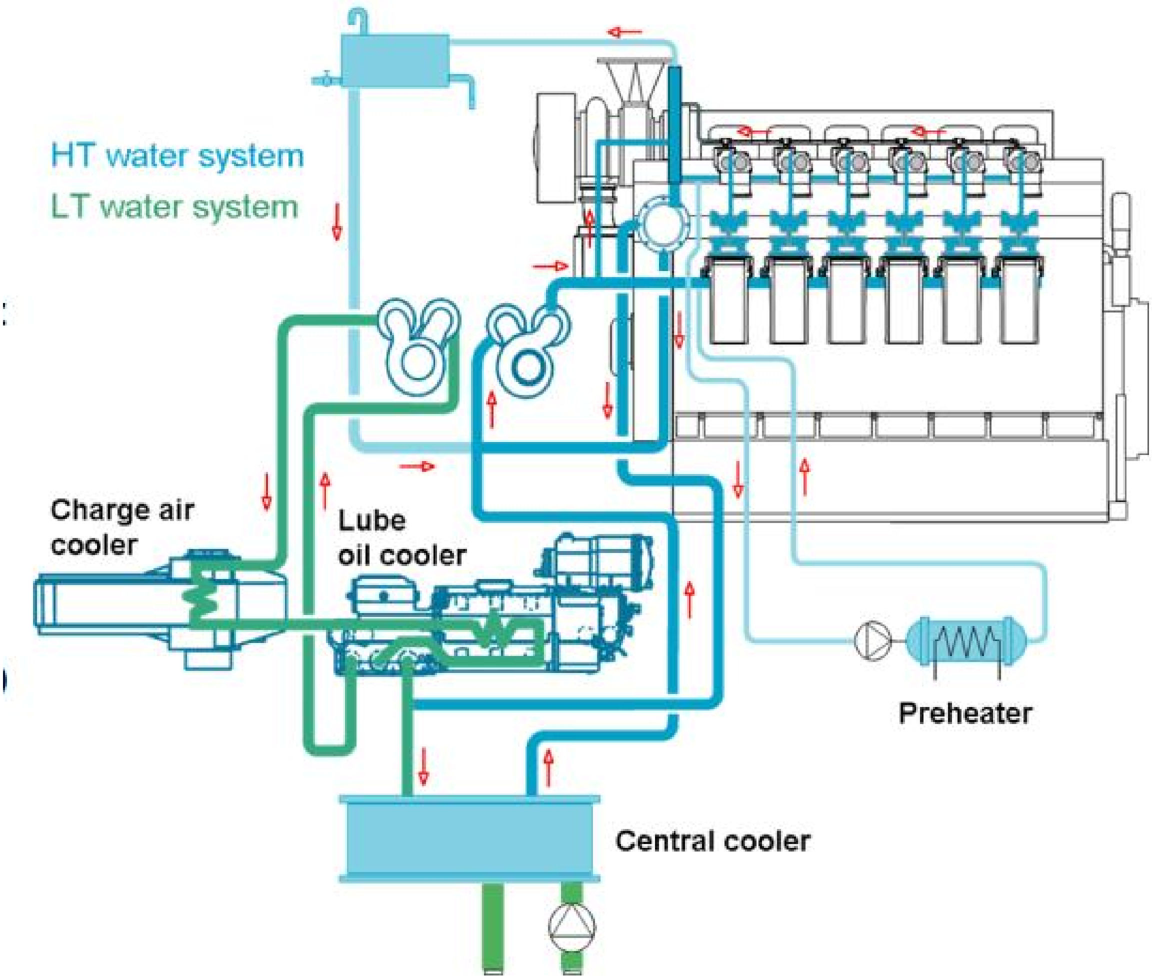
Picture 5. Typical compressed air system on a Power Plant (Wärtsilä 2018).

The starting air systems can be divided into two systems, control and starting because of different requirements in the engine and Auxiliary Systems.

4.3.4 Cooling water systems

Cooling water system usually consists of two circuits' which are low temperature and high temperature. These systems always continue outside the engine since the engine itself cannot cool the water temperature. The main function is to remove the heat generated by the engine and keep the air intake and lubrication oil system at the required temperatures. The secondary function is to preheat the engine block before start. (Wärtsilä 2018.)

Most components of a cooling water system have been installed in the auxiliary area. These systems contain, for example, a lot of piping, pumps, heat exchangers, and valves. As cooling water system is usually very large these components also require most space from auxiliary modules. In the following Picture 6 it can be seen that a preheater and a central cooler are typically in the auxiliary area and the rest have been installed on engine.

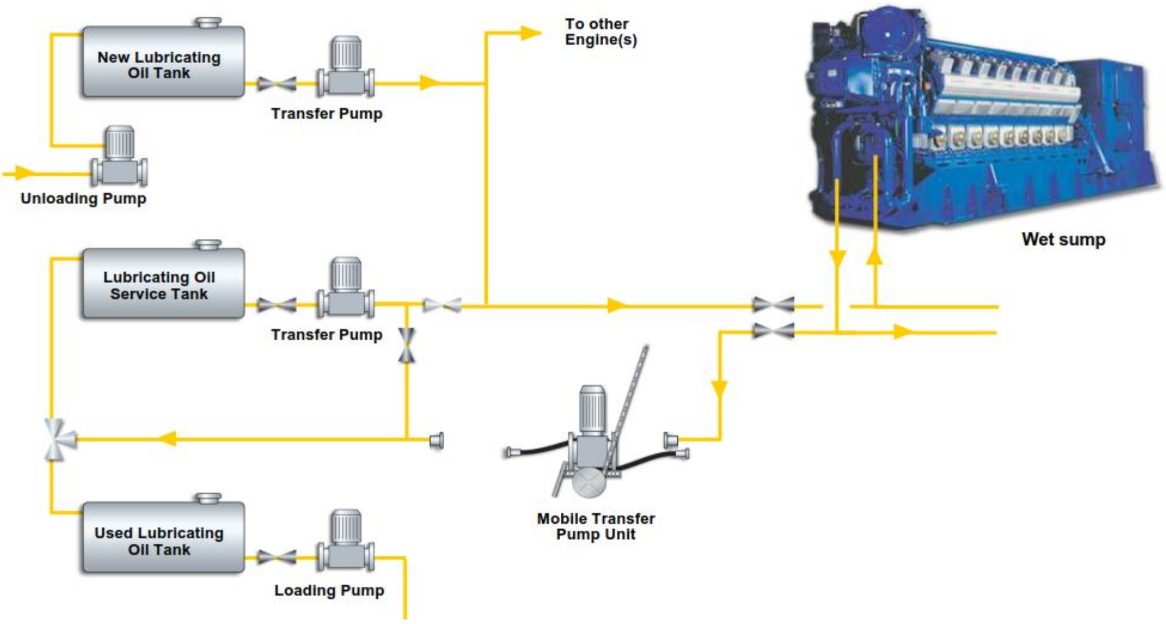


Picture 6. Typical cooling water system (Wärtsilä 2018).

Since the engine will heat the cooling water it has to be cooled again somehow. This cooling can be done by radiators in the ground, on the roof of a power plant or by central coolers in a ship.

4.3.5 Lubrication oil systems

The main function of a lubrication oil system is to feed the engine with clean lubrication oil at the required pressure and temperature. The system can be split into internal and external. The external system can vary depending on the components build in the engine and the type of engine, fuel qualities and application. Typical lubrication oil system can be seen from the Picture 7. (Wärtsilä 2018.)

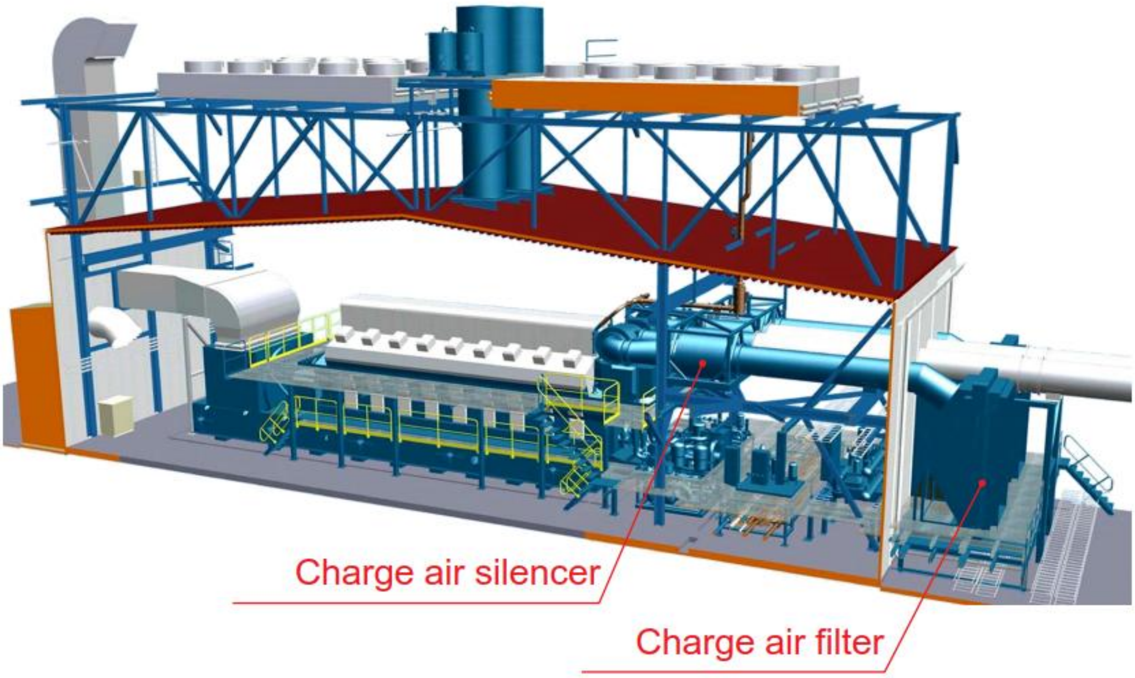


Picture 7. Typical lubrication oil system on a big Power Plant (Wärtsilä 2018).

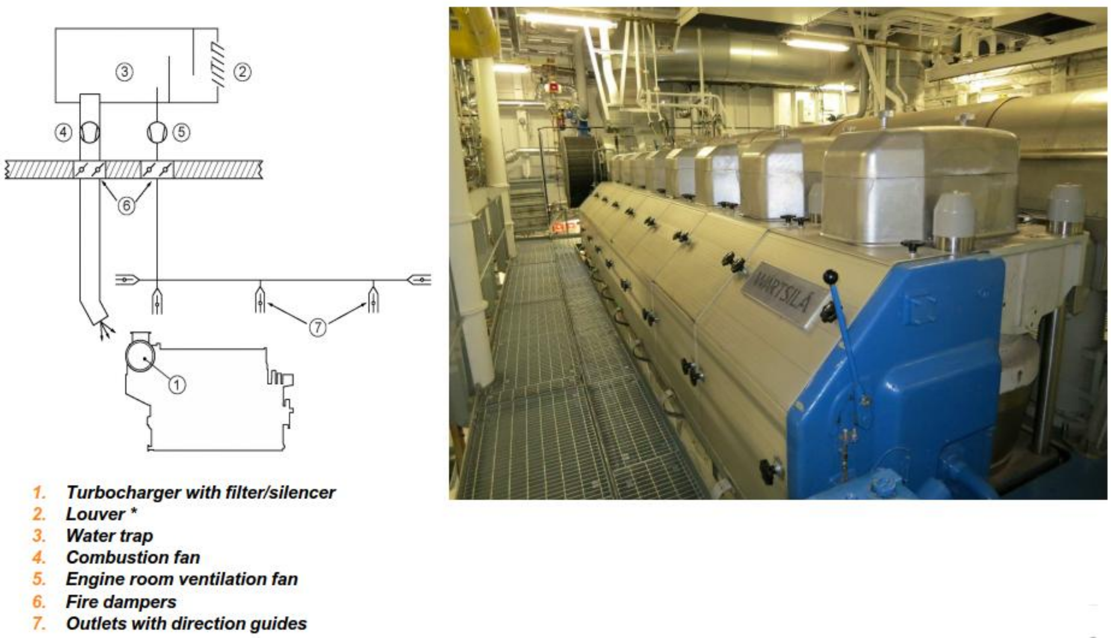
The system in a Power Plant and a ship can be very similar. The needed changes between these two applications are resulting from the used fuel, the engine and the running philosophy of the engine. There are also regulative authorities that control the way systems are designed: for the land based ones there are country and geographic regulations and for marine applications there are international regulative authorities such are IMO, International maritime organization.

4.3.6 Exhaust and air intake systems

The main purpose of an air intake system is to ensure that the engine will get sufficient amount of clean air. The system can consist of several different components but the main components, which are intake filters and charge air silencers, can be seen in Picture 8 and 9. These can be made parts of the modules to ease the construction of a ship or a power plant.

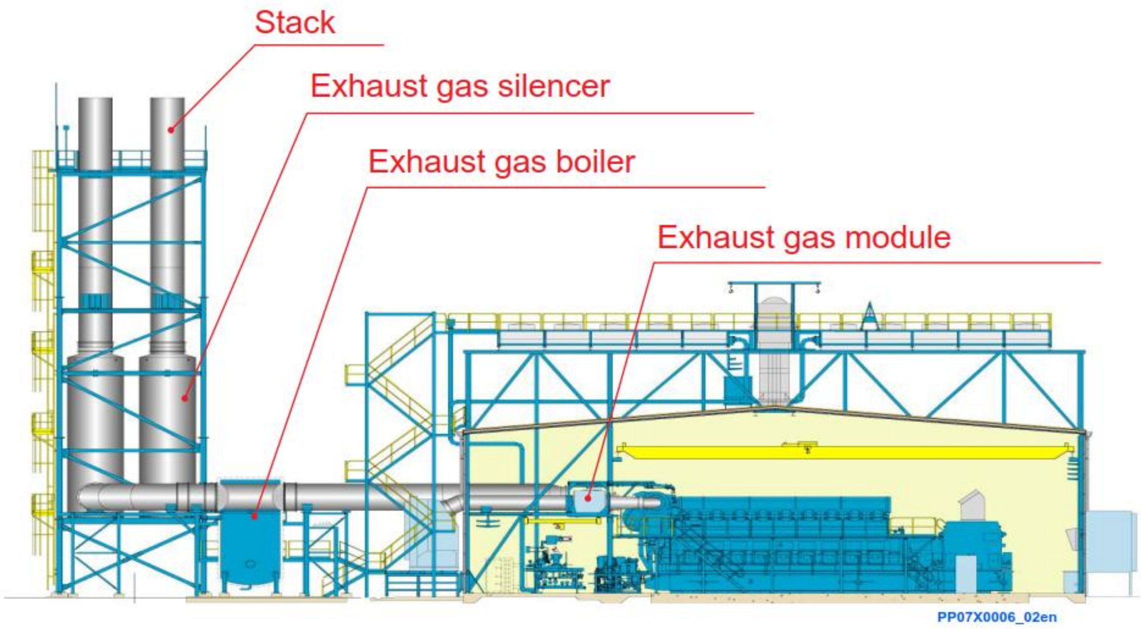


Picture 8. Typical air intake and charge air system of a Power Plant (Wärtsilä 2018).

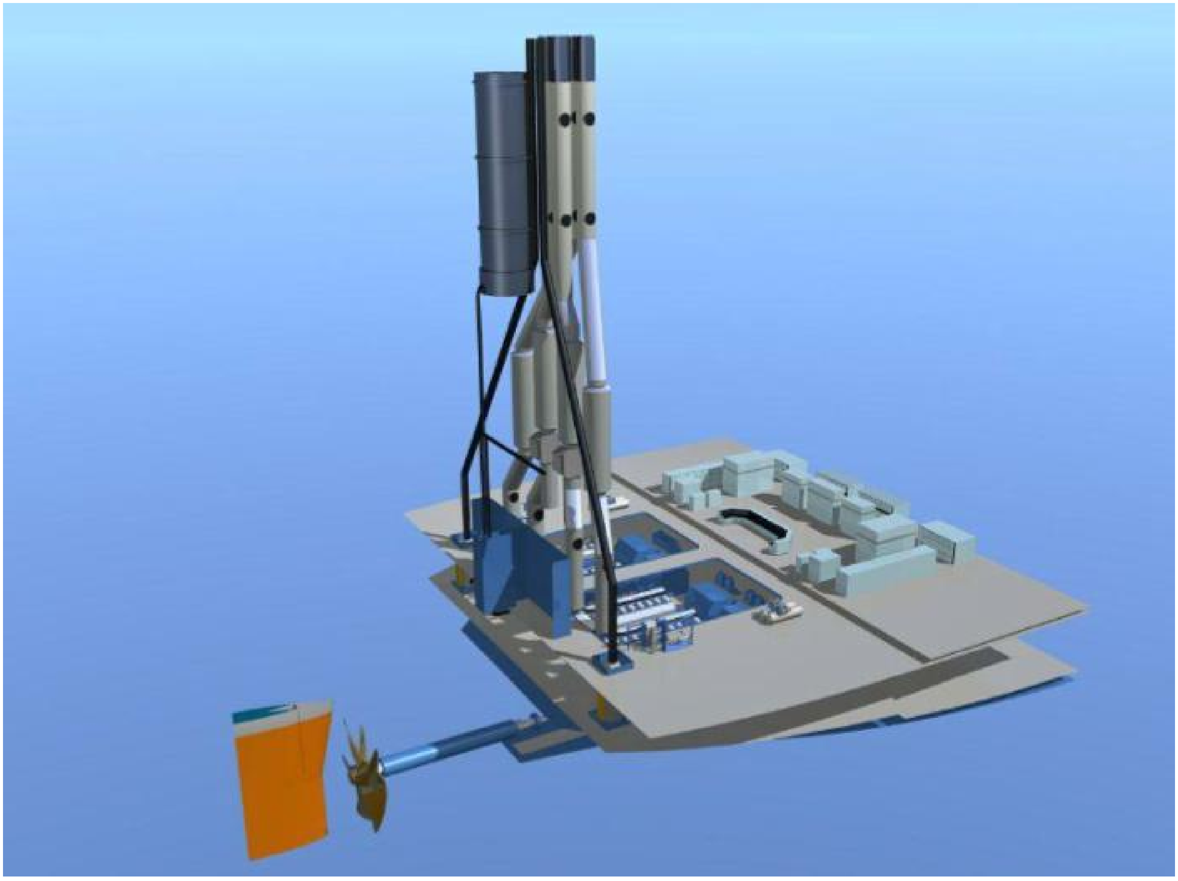


Picture 9. Typical air intake room on a ship (Wärtsilä 2018).

Pictures 10 and 11 show a typical power plant and a marine exhaust system. The construction of these systems is time consuming and usually requires big lifting equipment.



Picture 10. Typical exhaust system on a Power Plant (Wärtsilä 2018).



Picture 11. Typical exhaust system on a ship (Wärtsilä 2018).

5 VALUE BASED SELLING IN WÄRTSILÄ

Value based selling in Wärtsilä has been developed for several decades. The following sections mention only a few of those methodologies and are in no means a complete description of value based selling in Wärtsilä.

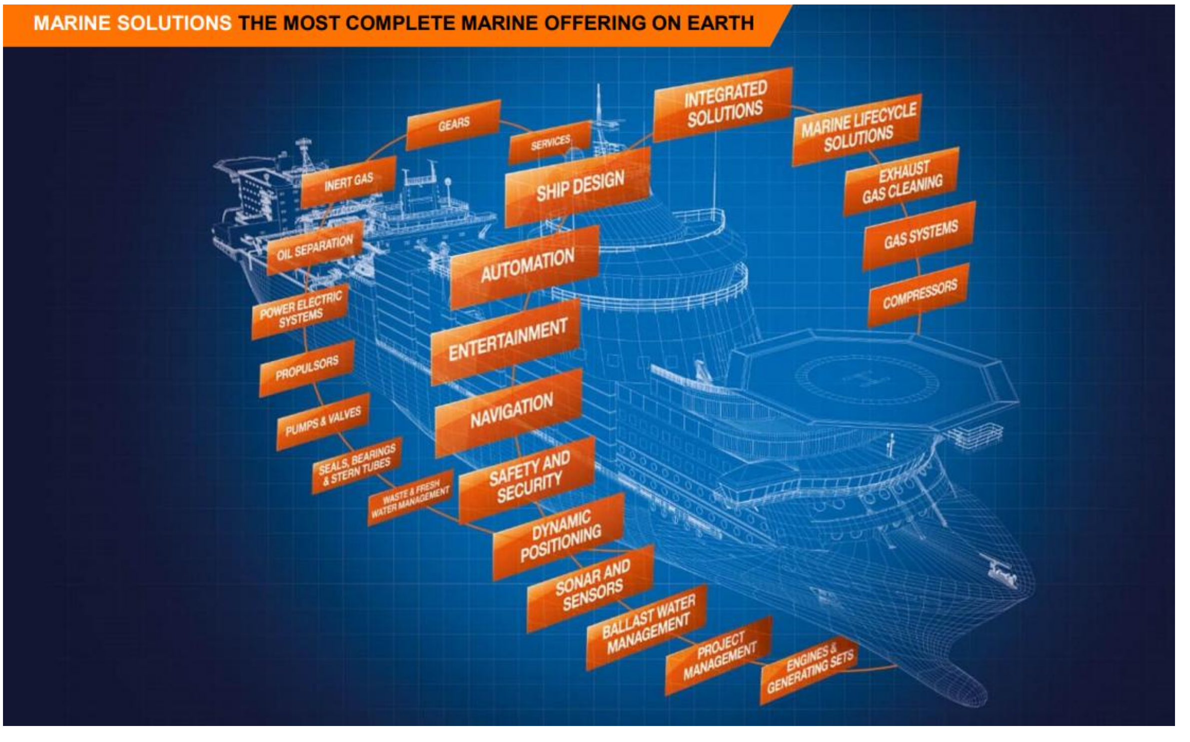
5.1 Introduction of value based selling in Wärtsilä

Over the years Wärtsilä has developed a lot of value based selling. In Energy Solutions value based selling starts from the customers' business model and can include, for example, a country's electricity grid modelling. Based on the customers' business model, and the grid behaviour and requirements, it's easy to start to offer solutions that benefit the customer. In Wärtsilä Marine business value based selling has been slower due to more traditional market. In the past, marine market was only about component deliveries. Shipyards did more work on their own, gathered all the required components and built them into a system of the ship. There were several different suppliers and none of them had a full portfolio to offer. In the past years with acquisitions and the development of their portfolio Wärtsilä has acquired the largest marine portfolio offering in the market. In marine business value based selling is more or less a full scope portfolio. The added value to customer can be that they can purchase all the needed components from Wärtsilä.

5.2 The value based selling at Wärtsilä Marine Solutions

Wärtsilä Marine Solutions has the most complete marine offering on the earth which can be seen in Picture 12. With a broad portfolio Wärtsilä can be a one stop shop offering all the equipment the customers need. The focus on this thesis is on the 4-stroke engines and the auxiliary equipment they need to perform their function. Wärtsilä Marine Solutions has developed a broad marine engine auxiliary portfolio that is controlled with an easy to use application called TERPS. TERPS is an abbreviation from Total, Engine, Room packages for Auxiliary Systems. It is a database of drawings, instructions, and manuals for components ready to be sold with annual prices agreements. (Wärtsilä 2008.)

The auxiliary equipment needed for the engine is similar weather there is a marine engine or a power plant engine in question. Even the components can be the same with only small differences coming from the organizations that are making rules for auxiliary equipment. In a Wärtsilä power plant the whole plant is made of modules that can be easily shipped, pre-manufactured, tested and inspected before commissioning at the power plant. This will increase quality, save on costs and speed up the commissioning of the plant. When talking about ships, the needs of the customers differ very much and a small tug boat does not have as much space as a large cruise ship. Therefore, the focus on this thesis is on the cruise customers.



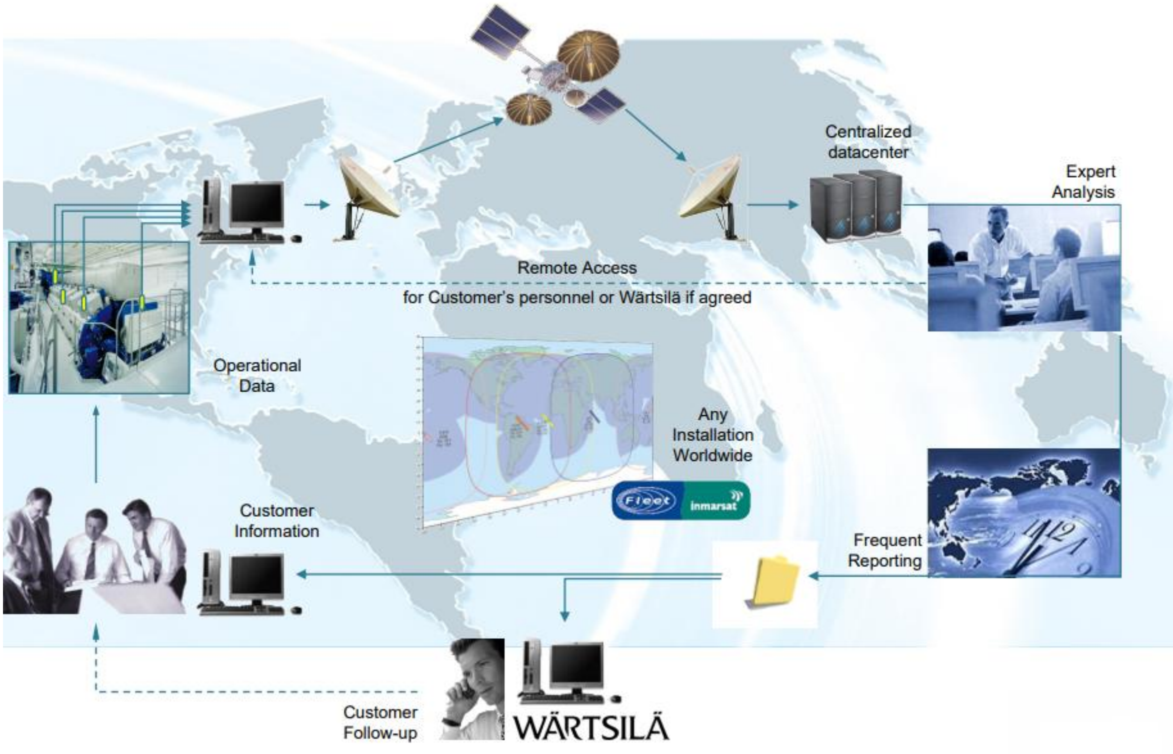
Picture 12. Wärtsilä marine portfolio (Wärtsilä corporate presentation 2017).

During the thesis work a new set of marine engines was started to be developed together with a set of auxiliary modules needed for engine operation. These modules are presented in more detail later on in the thesis. The benefits of a modular auxiliary portfolio for marine business area is explained more thoroughly in Chapter 6.2 which concentrates on the description of power plant auxiliary modules.

6 VALUE BASED AUXILIARY EQUIPMENT

During the development time of the new Wärtsilä 4-stroke engines it was discovered that the needed market requirements can only be achieved with a common rail engine and two stage turbocharging technology. This requirement again caused pressure on the engine design to design the engine with two stage turbochargers and fine filtration equipment. On top of these, it was decided that also quality, safety, operation and maintenance should be focused on, to give more value to the customer. The needed new technologies will be crucial for the success of new engine platforms.

On top of the previously mentioned qualities there is even greater need for added digital connectivity between the several systems involved in a ship or a power plant. Already now Wärtsilä has so called Condition Based Maintenance department (CBM) looking after all the delivered plants that are linked to WECS (Wärtsilä Engine Control System). The target of the CBM solution is to give guidance to engine operators on how to operate at the optimum efficiency and how to notice any deviation on the operation profile that should require service. By analysing the data constantly CBM can predict the maintenance need proactively instead of reactively. It also reduces unnecessary maintenance and extends the time between overhauls. Snapshot of the CBM communication matrix can be seen from the Picture 13. (Wärtsilä 2013.)

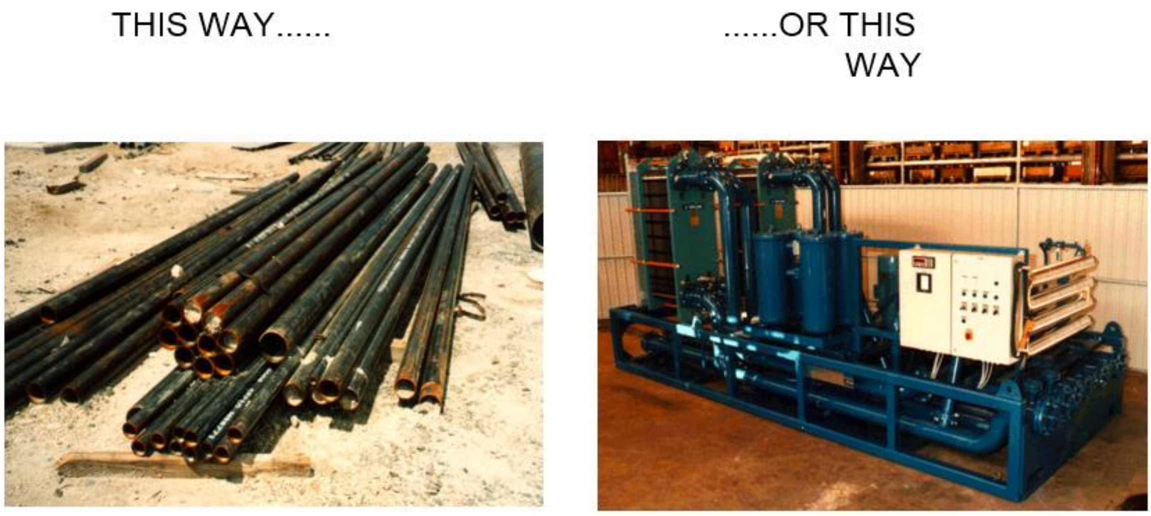


Picture 13. CBM communication (Wärtsilä CBM 2018).

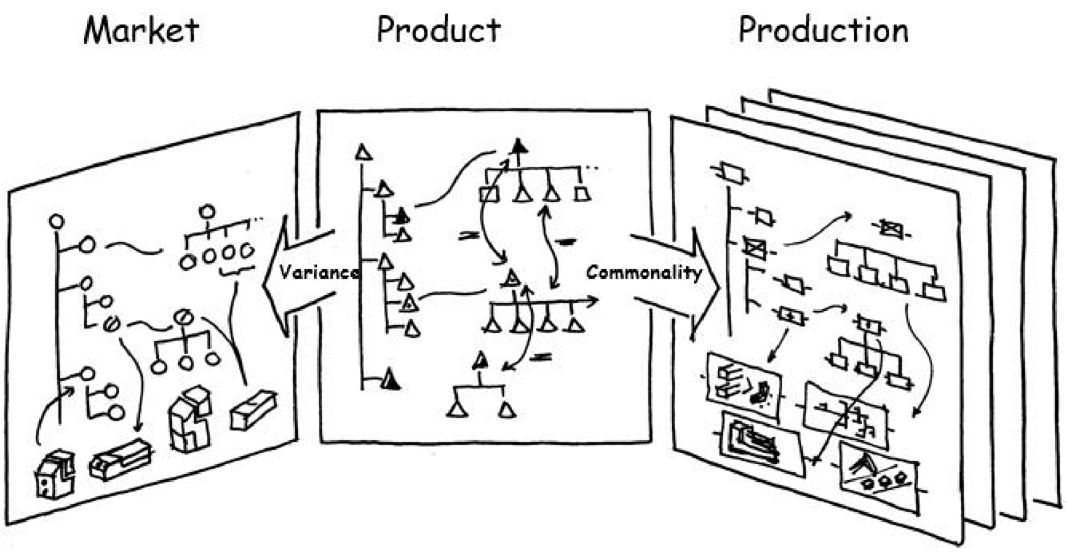
When the engine manufacturer has designed all the previously mentioned system functionalities the added value to the customer is obvious. The connectivity between the systems is designed ready and it can be ensured by pretesting and pre-manufacturing modules before delivering them to a ship or a power plant.

6.1 Description of power plant auxiliary modules

During the 1980s Wärtsilä started to make engine technology power plants. Right after the start it was noticed that building prefabricated units was needed. The first modules designed were pipe modules. These modules have been developed for several decades now and combine all the pieces of equipment that are needed for engine power plant operation. As Wärtsilä is split into different business lines, the technical people developing Auxiliary Systems that are not targeted to engines have also been split. Engine is the only link in between them. As engine development is time consuming and costly, the target is to develop an engine that will serve both business lines, but with own functions and design stages, to serve the needs best. In Marine Solutions the technology development teams are fairly small so the focus tends to be on the selling phase making process documentation for a ship Auxiliary Systems and selling individual components while in Energy Solutions there is more focus on the development of standard products to best serve the market needs. There is very little joint development between these two business lines, even though the engine is almost the same. Picture 14 shows why prefabricated modules could be a better way instead of doing more work on the site.



Picture 14. Piping to Power plant site and a prefabricated module (Wärtsilä 2011).



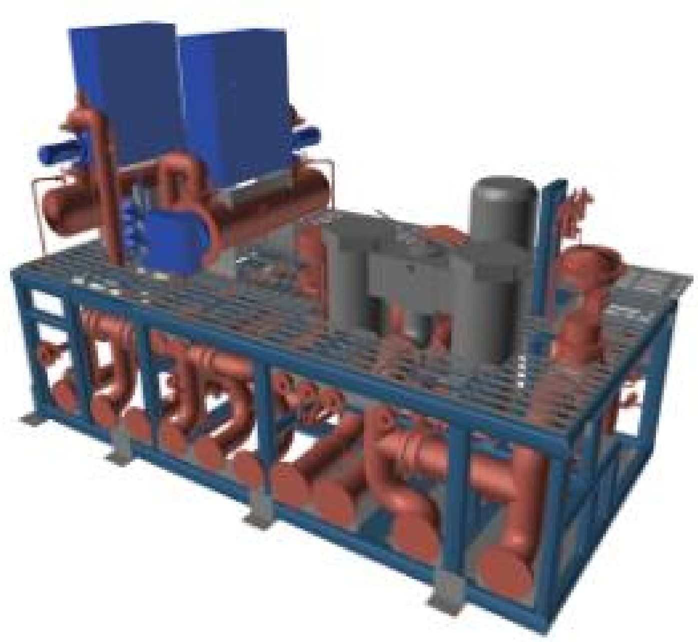
Picture 15. Modular portfolio matrix in Energy Solutions (Wärtsilä 2011).

> "Modularization is about using common sense and making the right choices and compromises. All the different interfaces have their own specific needs, and the end result is a compromise between these needs. Our primary purpose is fulfil our obligations to the customer, and our modular designs are integral to this goal." (Wärtsilä 2011).

The main purpose of modularization in Wärtsilä Energy Solutions business line is to make standardized interfaces, change management, with the customer always in mind. The goal of the modularization eventually is higher profit by reusing similar modules. Modular product architecture has also the following benefits:

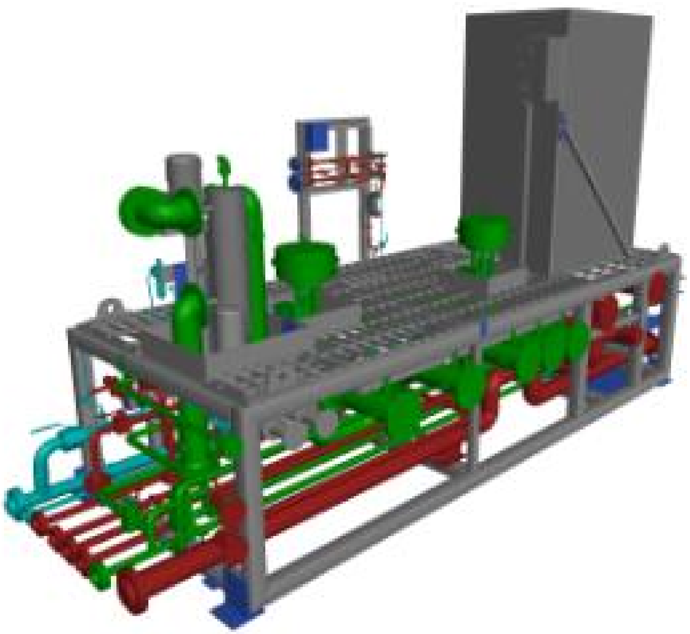
– less design, documentation, assembly and parts
– similar parts and less complicated specification
– more accurate prices for sales use
– controlled module manufacturing, painting, cleaning, and testing.

Some module examples from a power plant auxiliary modules are listed below:



Picture 16. W50SG EAM (Engine auxiliary module) 2.2 (Wärtsilä 2015).

Picture 16 show a typical W50SG EAM 2.2. W50 is an engine type used in power plant application and EAM is abbreviation from Engine Auxiliary Module. This module in constructed from steel beams carrying lubricating oil filters, a pre-lubrication oil pump, a high temperature water preheating unit, a low temperature water preheating unit, a pressure increasing pump and temperature control valves for cooling water and lubrication oil.



Picture 17. W32/34DF EAM (Engine auxiliary module) 3.0 (Wärtsilä 2015).

For a W32/34DF engine the modules are normally smaller than the previous module shown in Picture 16 since the piping and engine is smaller. In Picture 17 and example of W32/34DF Engine Auxiliary Module 3.0 can be seen. It is also constructed from a steel beams carrying control panel, cooling water through piping, temperature control valves, cooling water preheating unit, clean leak tank with emptying pump, turbocharger washing unit, instrument air filter, cooling water pressurizing pump, pilot fuel pipes with pneumatic shut-off valve and automatic lube oil top-up valve.

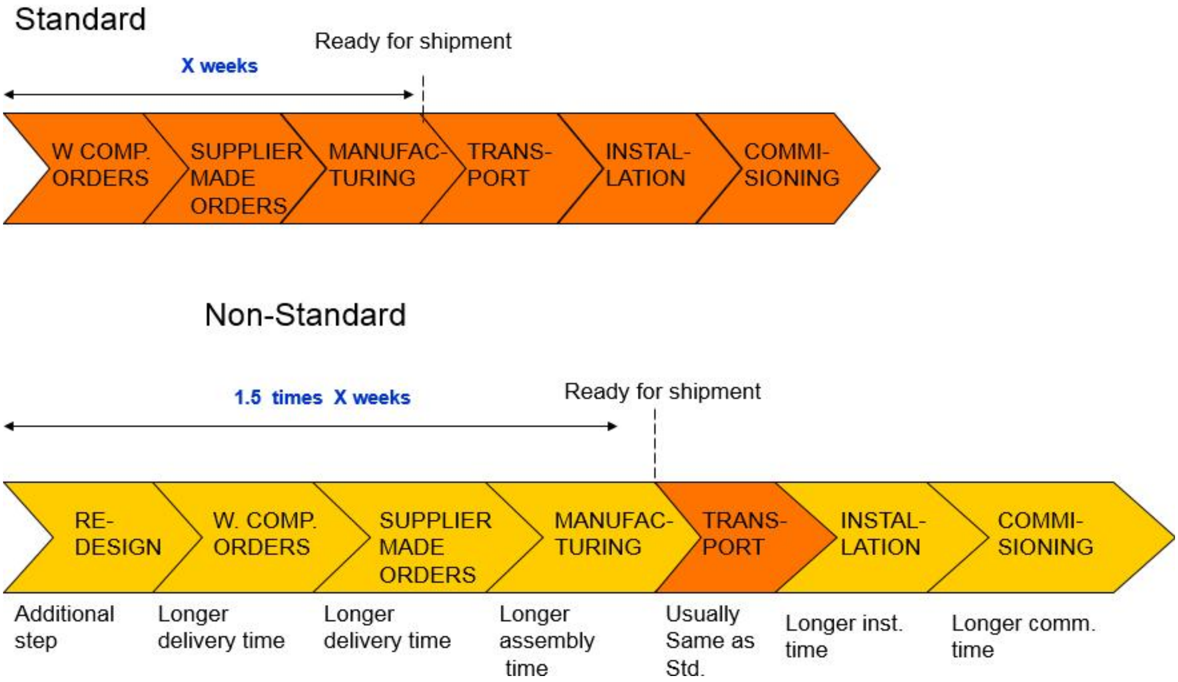
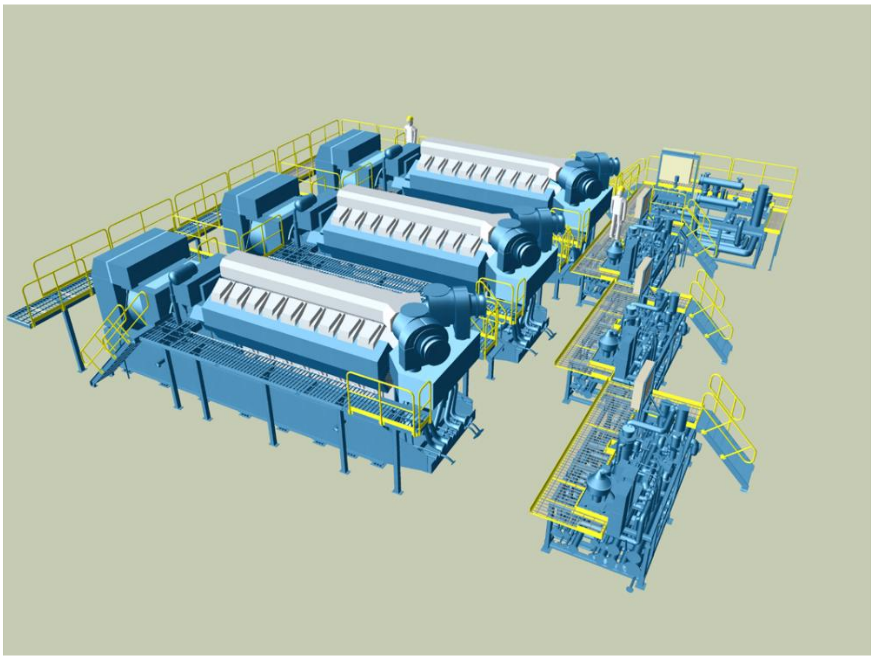
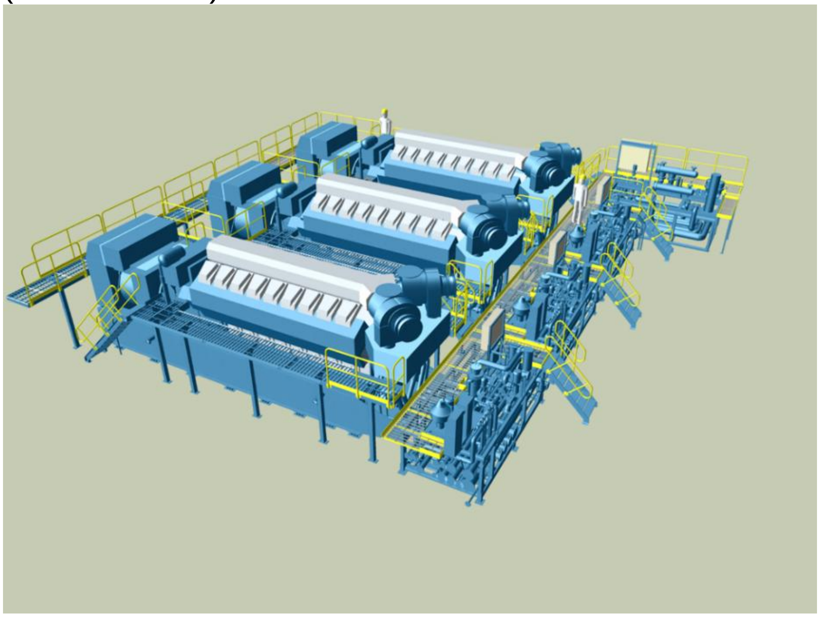


Figure 7. Standard modules vs non-standard modules timeline (Wärtsilä 2011).

Based on previous Figure 8, benefits for standardized modules are obvious. Shorter lead time can increase sales, smaller stock, less design work and better quality. Prefabricated modules also help on commissioning because components can be tested, flushed & inspected at module manufacturer before delivery to site. This leads to faster commissioning and higher quality power plants. Overview of the power plant modules fitted to an engine can be seen from next two Pictures 18 and 19.



Picture 18. Pre-fabricated Modules installation
(Wärtsilä 2011).



Picture 19. Finished Power Plant with pre-fabricated auxiliary modules (Wärtsilä 2011).

Picture 20. Pre-fabricated modules inside a Power plant engine hall (Wärtsilä 2015).

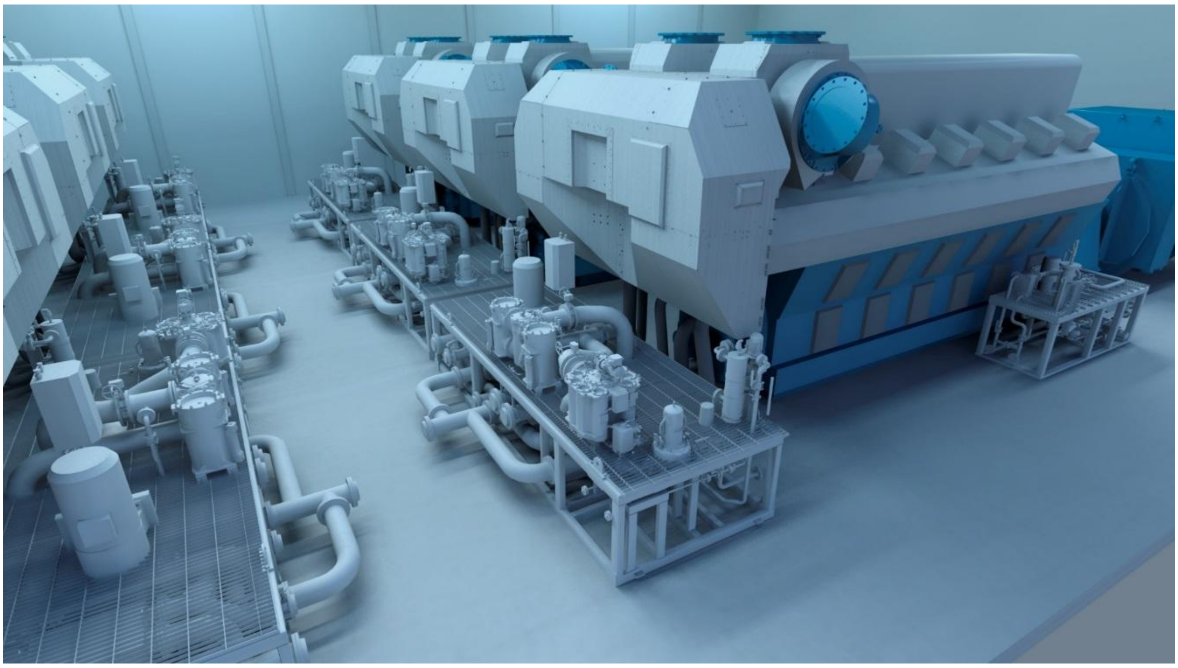
6.2 Power plant building sequence

Building a Power Plant starts with civil works by building a foundation. After that starts support beam structure building. Next in line is the steel framing that is pre-fabricated and has detailed installation instructions. After the steel frame usually overhead crane is installed and then roof. When the foundation has dried and the engine position is ready the installation of engine and auxiliary modules will begin. When roof is finished starts wall installation followed up by windows, rest of the walls and ventilation. Every sequence of installation can be done partly parallel to have as fast installation time as possible.

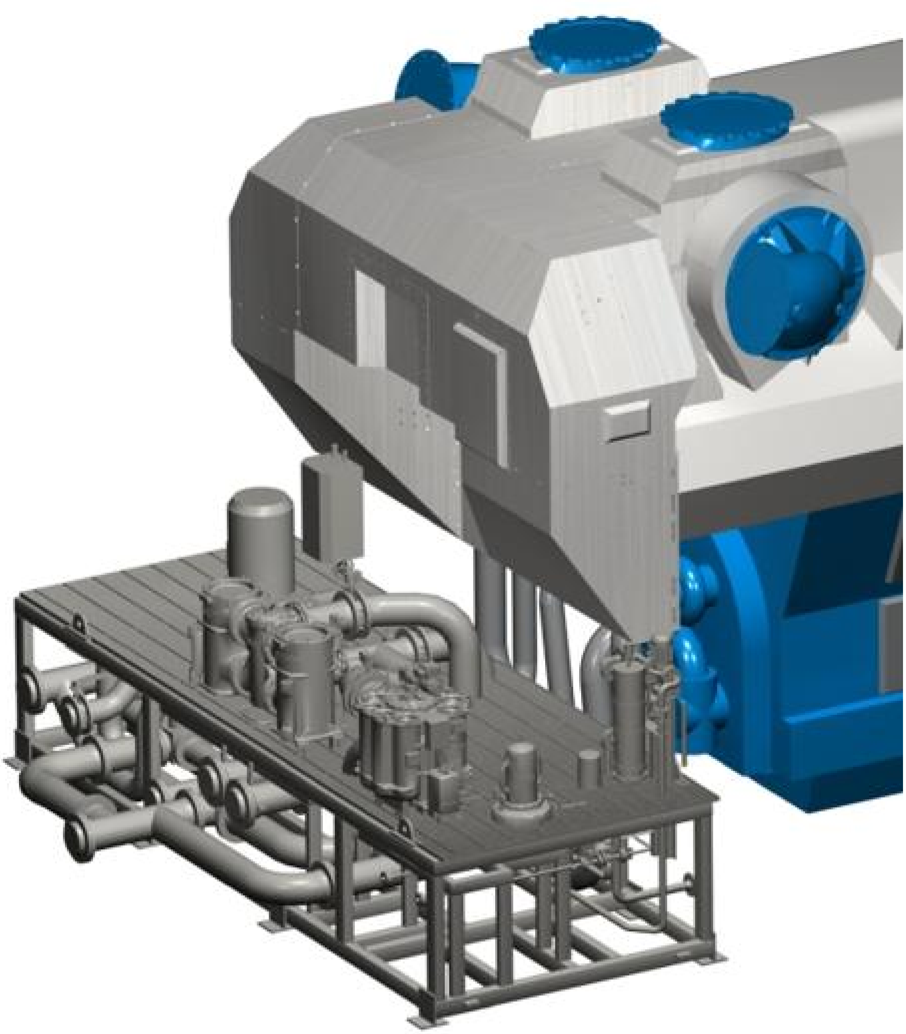
7 NEW MARINE AUXILIARY MODULE

In the thesis work it was decided to focus on marine customers with the most potential sales related to engine makers own design auxiliary modules. These were cruise shipping customers and yards. In cruise ships there are usually largest space available to fit a pre-manufactured modules. The smaller the engine is, more difficult it will get to install a ready-made modules. Smaller ships not only have smaller available space, but also very different customer requirement which will lead to customer specific design of ancillary equipment. Usually needed auxiliary equipment for a ship is in a separate room which will lead to long piping, slower process and bigger space needed. With the new requirements in mind to have compact engine room with auxiliaries. The auxiliaries can be fitted to the same room as the engines as they are in Wärtsilä power plants as well. This way the interface of engine can be kept similar as a power plant and the space available if as compact as it can be. From the previously written conclusions following rendered snapshots of new auxiliary equipment's build to modules can be seen. These rendered pictures are not complete, but they were used to discuss the topic with potential customer. Due to the information sensitivity the details are out of this thesis work. In the below picture there are four new Wärtsilä 4-stroke engine fitted into an engine room of a cruise ship. There are four since usually in marine there are rules that main engines of a ship has to be redundant. In a failure case two of the engines fail, two left would still be able to operate. On the same picture in the side of the engine there are smaller beam structure modules where Light fuel oil related equipment is installed called as Engine fuel booster, EFB. In the front of the engine there are second module, which is called Engine Auxiliary Module, EAM where most of the cooling water components are placed.

The components placed in the modules are all linked to the engine. Either mechanically by piping or electrically by automation system used to control valves, pumps, actuators etc. Most of the equipment installed in these auxiliary modules have an effect in the engine parameters. They can have an effect on engine performance, engine component lifetime and maintenance intervals of the engine. The new generation of 4-stroke engines require more focus on process design and automation integration due to the increasingly important emission, which often requires more sensitive components and more flexible automation software.



Picture 21. Newly developed auxiliary modules for cruise ship engines



Picture 22. Pre-fabricated modules in a ship engine room

The added customer value of these modules are: compact space, faster installation time, added digital integration to engine with control system, better control of quality, functionality and spare part handling. There are many other benefits as well, which are partly written in the conclusions part of this theses. Due to the fast nature of the sales discussion with potential customers, and the high workload during the thesis writing period, the progress to develop these modules did not follow all the guidelines written in the theoretical part of this thesis.

The work for any development project starts from a concept study. This work is not detailed but gives the needed input to start a detail phase. First phase of the development work of new marine auxiliary modules started by evaluating the engine requirements. New set of engines requires lots of detailed information on process parameters, functionality and most often even tested systems and components. Some of the work can be simulated, but in most of the cases some testing is needed. Concept in this project involved a lot of reusing the knowhow created by power plant applications. These power plant applications are already delivered with Wärtsilä designed auxiliary modules and they have an automation control system designed by Wärtsilä. The concept for new marine auxiliary module evolved very quickly by discussing what do we need to change from an energy solution process, components and requirements point of view when going from a land base power plant to marine application. Starting point for a system is usually process and then detailed selection on components, suppliers and automation control. This concept work was done together with a third party engineering company who already had several years of experience from a power plant applications. Due to the fast nature of the project the concept did not evolve into any other than the first good concept. Work started with a process diagrams, by checking what we need to change form a power plant in order to supply the engine with fluids and air required. Not all changes came from the difference between marine and power plant engine, but also from the new 4-stroke engine.

To reflect on the theoretical part of this thesis new product development consist of six phases. These phases are planning, concept development, system-level design, detail design, testing and refinement, production ramp up. (Ulrich 2012.). This is also very much align to what development actions were done. Following phases are describing what was done in each phase and what should have been done to fully utilize the theoretical part of capturing the value in product development phase.

In the **planning** phase the idea was brainstormed in several meetings and coffee table discussions and ended up in brainstorming the idea with Marine Solutions departments responsible of marine auxiliary equipment. From previous projects we already had very good knowhow on systems, components, frames for components, marine rules and regulations. Next phase was **Concept development** which was done together with the 3rd party engineering company. In the concept phase the layout, frames, components had already been more or less selected which lead to quick first version rendered pictures that can be used during sales phase to discuss with the customer. Concept phase was very quick due to the experience from earlier projects. Concept phase usually involves selecting target market, which we had selected already earlier. Usually it also involves several concepts out of which the best is selected, but since the idea was so clear only one concept was done by utilizing the existing knowhow from power plants. In the concept phase much focus is put to process design since that is the most important factor of these new modules. The modules alone are not an own functioning product, they become as a product only when they are installed to the system linked to the engine. Next phase is then **System-level design**. During system level design phase it involves component selection and a preliminary plan for production and assembly. Detail design, testing and refinement and production ramp up were out of this work and should continue if the idea will materialize into actual sales.

8 CONCLUSIONS

Malinen (1998) makes a conclusion in his doctoral thesis that any work that is not part of the core business of a shipyard should be outsourced to speed up construction and to focus on the core business, that is steelworks and assembly work to construct a ship. Therefore, the auxiliary system components can and should be outsourced especially to the engine maker. The engine maker will then have the sole responsibility for the ship's engines and the auxiliary equipment. This outsourcing activity will lead to high added value with increased digitalization, system integration and shorter lead time with more focus on the core business. This will then create even more business, and the quality of sea-trials and commissioning will be higher. If the auxiliary equipment is outsourced to a 3rd party company the risk of misreading and misinterpreting product manuals and guides will be higher and more failures can happen. The engine maker will know in detail what kind of equipment is needed to make the optimal auxiliaries. Those can be pre-tested and tuned ready for a commissioning. If there is a failure in a component selected by the shipyard, the failure is most probably visible in the engine system because the system on engine is connected to the auxiliary system.

A shipyard is responsible for the ship construction but the end customer will then be left with the auxiliary equipment in operation for several decades. If the engine maker can make a modular product structure that can be easily updated, this can lead to continuous improvement and continuous flow of updates for both the engine and the auxiliaries, which will benefit both the end customer and the engine maker. There are not many suppliers in the world who can supply the whole chain from propulsion to an engine and their auxiliaries, but Wärtsilä is one of them. This way the needed turn-key can be like a power plant EEQ, engineering and equipment delivery where a shipyard is building the surrounding walls and the needed extra appliances.

With all the factors in mind, can the engine maker be without their own auxiliary equipment supply, especially in the new era of efficient high technology 4-stroke engines? Would it be reasonable to buy a car with a partly completed engine, where the rest of the components would need to be purchased elsewhere and the buyer of the car would then be responsible if they do not fit together with the engine?

Based on the theoretical part of this study the essential point for management to consider is, to make a visual corporate level tool for the technical function management system. This way the stakeholder value can be captured and the existing designs can be reused, managed and controlled. Quality, delivery and cost are ensured since only the needed variants can be left to the portfolio. This will lead to a lean portfolio of auxiliary equipment's. Together with this tool the way of working should be changed in order to capture the value at an early phase of product development, not when the product is fully designed and tested, but when the R&D team starts to draft the needed technical functions for a new product. The R&D team's management system should be developed with the theoretical background of value management and the lean value creation part of this thesis, which will form a continuous flow of value creation.

When studying the organization structure of R&D departments in Wärtsilä which are working with auxiliary modules for marine and power plant applications, it is obvious that it could be streamlined. Now they are separated by the business area and the link between is the engine. If the departments developing auxiliary modules would be under one management area the way of working could be even more streamlined. Now different people with different objectives form and develop different products even though the purpose of the auxiliary equipment is the same. Auxiliary equipment consists of machinery that is not possible to install on an engine and to have as a part of the engine delivery. There are, of course, marine and country specific rules and regulations, but that does not mean the marine auxiliary products could be similar. The engine is already very similar and that is managed by one large specific department, the engine technology. This way the overview of these two markets can be united and a clear strategy can be formed. With a good tool for variation management the products targeted to marine and power plant use can be made as configure-to-order with similar functions, taking full advantage of these two market areas, marine and power plants. This will lead to higher volumes of components, and to better control of quality, delivery and management of these module variants. This team can then make a strategy on how to develop the auxiliary equipment to best serve the end product which is, in this case, the engine installed in a ship or a power plant. This will also lead to a leaner supplier portfolio, and the same existing supplier base of auxiliary modules can be utilized even more. Cost savings can then be achieved by having a larger scope for the module supplier and a higher utilization rate of the suppliers.

Lean value management in product development is not used to its full extent. There are some tools in Wärtsilä which are used to guide the development of new products, but these are not taken into complete use. There is a bonus paid if for example employee introduces a new idea that can be patented. Or are senior experts who might get an annual individual bonus paid based on the individual and company performance compared to the set targets. These are good starting points, but do not really guide the product development towards value creation, but rather towards achieving the set goals. There should be set targets for every individual or team in the beginning of a new R&D project or product development. These targets should be specific, measurable, achievable, realistic and tangible. The targets should be transparent to everybody and they should be reflected in the annual development discussions as the set targets. The achievements of teams or individuals on capturing value creation during product development should be registered and celebrated in order to increase knowhow on value creation.

The real work for this thesis began in 2017, by realizing that we should have own design marine auxiliary module in new engines, similar to power plant modules developed for decades. This idea has already before that popped up several times during team meetings, corridor conversations and the way of working discussions. Now that the study is final the outcome is much wider than expected. The need for new function based development tool and the need to modify current way of managing team or individual targets did not come to mind previously. The needed effort to capture stakeholder value is difficult when there are several different opinions on how the customer and internal organization should be managed and usually people have been working with the same area for decades. This long experience is an asset, but it can also lead to a narrow view on how things should be dealt with. In a large corporation there should be mandatory job rotation periods to open eyes more to corporate level issues and opportunities. This would create value for the company in terms of new knowhow which is difficult to capture. The portfolio of auxiliary module products between Marine Solutions and Energy Solutions business areas is also fairly large with several variations of the product itself which is the engine where these auxiliary modules are connected. The biggest challenge discovered during this thesis project was that these two business lines do not discuss enough. They have different strategies and develop different products because there are no corporate level tools for managing the product variation easily. The need for developing this way of working is highlighted in the corporate strategy, Wärtsilä wants to be a total solution provider. One easy way to manage this is that the R&D tools, where product variation is managed, would be used on corporate level, and this would lead to transparency in the whole chain of departments working with the same goal.

The new auxiliary modules' concept for marine customer developed during this thesis work forms a new way of thinking. Normally for a cruise customer, the auxiliary equipment is installed separately in a separate room, but the meetings with end customers had an obvious direction. We need to develop the way of working towards faster installation, easier assembly for a marine business. This can be done by installing most of the auxiliary equipment directly to the engine in a similar way as Wärtsilä has done with their land based power plants for decades. This way the space is optimized in the engine room, and the cruise customer will have more room for hotel space which will be an added value factor when selecting this way of working.

There is an increasing need to serve customers better and one very important factor is service. Since the engines and their equipment is built to last for decades, it is necessary to understand how the total process works with the engine. This means that all drawings, design data and the details of the auxiliary equipment is available so the process can be fully understood and developed. There can be even several auxiliary equipment suppliers which will create more complexity to the whole process. If the engine and the auxiliary equipment are supplied by one company, there is better control of the total chain related to the operation of these 4-stroke engines in the ship. Also the upgrades related to the process or components are easier if there is just one supplier.

9 NEXT STEPS

The study is short and should continue especially on the topic how to capture stakeholder value during product development process. Usually the fast nature of product development projects will lead to narrow view on stakeholder value and should be studied more closely. Also shipyard business has not been studied that much which was evident when trying to find theory and previous researches. Due to complex nature of the ship building business, it would be a good area to study more closely.

Modular product structure is an excellent way to make the product structure into easily developed, updated, managed continuous R&D activity without the need for long and time consuming R&D projects. New functions developed can be easily transferred to the existing product portfolio with planned ramp up times to manage risks caused by new technologies, suppliers etc. Modular product structure should be done in a system that is visual, transparent and easy to manage. The decisions of module drivers should be easily accessible for everyone working with the product structure. This way the decisions can be discussed, challenged, and new drivers can be implemented easily according to customer, market or technology needs. If the product structure is done in easily manageable system the all the changes required to the product structure are easy no matter how complicated the product structure is. The systems involved in a ship or a land base power plant are so complex that there is a clear need to make a system where the added customer value is easily captured. By analysing only the total system the added customer value is lost with all the different functionalities the systems possess. Even though Wärtsilä Energy Solutions business line auxiliary equipment has been developed into modular portfolio, there is room for improvement by utilizing the key features of modularization according to guidelines expressed in controlling design variants section of this thesis.

By making an easy to use transparent product development system that can be used in every business unit in the company the knowhow can be transferred from one expertise area to another. This will lead to more cooperation between departments and can possibility utilize same designs and same modular architectures.

The needed outcome of the thesis was as expected, but the progress during the work went in sequences between theoretical part and construction of the research. Construction of the work should be more theory first and then construction, but in this thesis theoretical part came in the last stage. The theory part should be studied in the beginning and then move on to the next phases of building the concept, but this was not possible due to the fast nature of first concept studies on marine auxiliary modules. The knowhow studied during this work can be utilized in all product development and especially in complex systems development projects. Change in position from the writer during the process was not good on the progress of the thesis, but eventually lead in more open view on how the other business units are working with modules in Wärtsilä. This made the study more complete with different perspectives.

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