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Title: **Design of a Workflow Management System for the engineering process of Damen Schelde Naval Shipbuilding**

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Title (in Dutch) Ontwerp van een Workflow Management Systeem voor het ontwerp proces van Damen Schelde Naval Shipbuilding

Assignment: Master thesis

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Date: January 07, 2014

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Subject: **Design of a Workflow Management System for the engineering process of Damen Schelde Naval Shipbuilding**

Introduction

Damen Schelde Naval Shipbuilding is delivering naval vessels which can be divided in two product groups: the Combatants and Offshore Patrol Vessels, and the larger Amphibious Support Ships and Naval Auxiliaries. The naval vessels are characterized by a high integration of different systems onboard and are customizable by client. The naval vessels are most of the time one-offs or small series. The delivered naval vessels are well-known for their high quality and the delivery on time.

The engineering process is an engineer-to-order process and the delivering time of a naval vessel will be up to five years. DSNS is system integrator during the project and is responsible for all engineering information. More than 50 suppliers and several subcontractors take part in the project.

Problem definition

The market for the naval vessels will change from Europe to Asian countries. This new markets demands competitive prices and local production in combination with transfer of technology. The efficiency of the engineering process is attracting more attention, as consequence of the decrease of engineering budget. The requirements for engineering becomes: lowest cost and delivering on time. To achieve these requirements the engineering process has to increase the productivity. Current Workflow Management System doesn't comply with these requirements.

Assignment Description

"Develop a Workflow Management System that is able to manage the planned and ad-hoc information flows and contributes to:

- Lower cost

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- Lower cost
- Increased efficiency of engineering
- Identical or shorter throughput time of engineering"

Execution

- Analyze current engineering process by Damen Schelde Naval Shipbuilding according the Delft System Approach.
- Analyze current Workflow Management System.
- Define the desired Workflow Management System.
- Implementation proposal of the Workflow Management System in current engineering process.
- Study of relevant literature.

The professor,

Prof.dr.ir. G. Lodewijks

Supervisor,

Dr.ir. H.P.M. Veeke

Preface

This thesis is the completion of the master specialization Production Engineering and Logistics, part of the master Transportation Engineering and Logistics of the Technical University of Delft. This research proves the ability of the student to analyze a process, defining of a problem definition and give a proper solution for that problem. This thesis is the result of a research of the engineering process of Damen Schelde Naval Shipbuilding and defines a required Workflow Management System.

Readers who do not known Damen Schelde Naval Shipbuilding can start reading in chapter two. Chapter two contains a description of products and markets, the engineering process and current engineering management. Readers who are interested in the result of the analysis can start reading in chapter four, which contains the conclusion of the analysis of chapter three. Chapter four also contains the requirements for the Workflow Management System. Chapter five contains the definition of the Workflow Management System, where after in chapter six is described its implementation. The financial analysis can be found in chapter seven and the reports end with the conclusion in chapter eight.

I would like to thank Damen Schelde Naval Shipbuilding with the delivery of the subject of this thesis. Firstly, I would like in particular to thank René Meijn, supervisor of DSNS. Despite of your busy job you always make time available for questions. Secondly, I would like to thank Hans Veeke for supervising me on behalf of the TU Delft. Finally, I would like to thank my family with supporting me during my graduation period and study at the TU Delft.

Kruiningen, January 2014

Christian van Westenbrugge

Summary

Damen Schelde Naval Shipbuilding (DSNS) is part of the Damen Shipyards Group. DSNS is delivering naval vessels which can be divided in two product groups: the Combatants and Offshore Patrol Vessels and the larger Amphibious Support Ships and Naval Auxiliaries. The naval vessels are characterized by a high degree of integration of different systems onboard and are customized by client. The naval vessels are most time one-offs or small series. The market for the naval vessels changes from Europe to Asian countries. This new markets demand competitive prices and local production in combination with transfer of technology. DSNS has therefore developed the modular shipbuilding strategy.
The question which is the basic for this thesis is: "How is current Workflow Management System and does the current system complies with current project requirements: delivering on time, high quality, lowest cost?"

The delivering of one-offs customized naval vessels requires an engineer-to-order process. The growth process of engineering can be characterized by highly interrelated engineering activities, planned and ad-hoc information flows. The engineering process has to increase the productivity to lower the costs of engineering. The analysis of the engineering process results in the following requirements:

- Addressing engineering information to project participants in such a way that: firstly, the project participant receives the right engineering information and secondly, shortens the lead time between releasing and receiving of information.
- Controlling of the ad-hoc information flows to decrease the impact of them by analyzing the ad-hoc information flow and considering a cost effective and efficient solution which has the lowest impact on the total costs and delivering time of the project.
- The applied concurrent engineering approach requires the assignment of maturity levels to engineering information. The maturity level has to be assigned in more detail to parts of engineering documents.
- Implementation of manufacturing engineering which increases the efficiency of the engineering process and decrease the lead time between engineering and production.
- Disruptions of the engineering process have to be evaluated to improve the engineering project process of DSNS. The engineering disruptions, raised in ad-hoc information flows, have to be traced back to the source of them.

The assignment description becomes:
"Develop a Workflow Management System that is able to manage the planned and ad-hoc information flows, which contributes to:

- Lower cost
- Increased efficiency of engineering
- Identical or shorter throughput time of engineering"

The Workflow Management System (WMS) will have a product-centered structure, with making use of current implemented Schelde System Work Breakdown Structure (SSWBS). The product structure is defined with use of a Product Relation Matrix, which contains vertically systems and horizontally system parts. The relation of system parts (components) to the system of the naval vessel are defined with functional and interface relations. The dependencies between system parts are defined by the relationship of both system parts to a similar system. The matrix is used for the following aspects:

- Firstly, the engineering workflow is defined as all engineering transformation functions applied to one relation. The relation value is the specification of a relation in an engineering document by product parameters. The engineering documents and activities are defined with use of sub- and aspect system of the Product Relation Matrix. The sub- or aspect system contains a collection of relation values.
- Secondly, the relation values are assigned with a maturity level. The relation value evolves with every step of the engineering process. From a global description into the contract specification into a detail specification for ordering until a 3D CAD model for detail engineering. The maturity level will be indicated on every relation value from 'Unworked' to 'Approved'.
- Thirdly, the Workflow Management System supports the engineering change procedure. The engineering change propagation can be analyzed with use of the Product Relation Matrix. After listing all affected relation values, the solution can defined in a meeting.

Above procedures are supported by the assignments of tasks, sending of notifications to the project participants. Addressing of the engineering information is performed by using the link between the relations and the engineering activities.

The Workflow Management System contributes to:

- A higher efficiency of the engineering process. The product, defined in the Product Relation Matrix, is able to address the engineering information to the engineer. Furthermore, the engineer is supported with a dashboard which displays the available engineering information and tasks which have to be performed. The Workflow Management System supports the engineering change procedure.
- The costs for the engineering process will decrease after earn back of the investment for the design and implementation of the Workflow Management System. The return on investment will be about two to three years. This can only be achieved with combined implementation of WMS with the new ERP software 'IFS'.
- The throughput time of engineering will decrease. Firstly, the quick addressing of engineering information decrease the throughput time of engineering. Secondly, the Workflow Management System will result in less rework. Thirdly, the handover of engineering changes to production will have been shortened. The implementation of maturity levels in the 3D CAD model will make it possible to use the 3D CAD model for communication of engineering information.

Samenvatting

Damen Schelde Naval Shipbuilding (DSNS) is onderdeel van de Damen Shipyards Group. DSNS levert marineschepen welke kunnen worden onderverdeeld in twee productgroepen: fregatten en offshore-patrouillevaartuigen en de grotere Amfibische Ondersteuning Schepen. De marineschepen worden gekenmerkt door een hoge mate van integratie van verschillende systemen aan boord en zijn klant specifiek ontworpen. De marineschepen zijn meestal eenmalige bestellingen of kleine series. De markt voor de marineschepen zal veranderen van Europa naar Aziatische landen. Deze nieuwe markten vergen concurrerende prijzen en het toepassen van lokale scheepsbouw, in combinatie met de overdracht van kennis. DSNS heeft hiervoor de modulaire scheepsbouw strategie ontwikkeld.

Naar aanleiding hiervan is de volgende onderzoeksvraag gesteld: "Hoe is het huidige Workflow Management Systeem en voldoet het huidige systeem aan de project eisen: levering op tijd, hoge kwaliteit en lage kosten?"

De kleine ordergrootte van marineschepen vereist een engineer-to-order proces. Het groeiproces van ontwerp kan worden gekarakteriseerd door sterk onderling samenhangende activiteiten, geplande en ad-hoc informatiestromen. De productiviteit van het ontwerp proces zal moeten worden verhoogd voor lagere ontwerpkosten. De analyse van het ontwerpproces resulteert in de volgende eisen:

- Adresseren van engineering informatie naar projectdeelnemers op een zodanige wijze dat: Ten eerste, de projectdeelnemer de juiste informatie ontvangt en ten tweede de doorlooptijd tussen vrijgave en ontvangst van informatie wordt verkort.
- Management van de ad-hoc informatiestromen om de gevolgen voor kosten en doorlooptijd te beperken. Dit is mogelijk door het analyseren van deze informatiestromen en het kiezen van een kosteneffectieve en efficiënte oplossing.
- De toepassing concurrent engineering vereist de toekenning van betrouwbaarheid indicaties op engineering informatie. Voor een hogere mate van detail hierin dient de inhoud van de documenten verder te worden gedefinieerd in kleinere delen. Deze delen kunnen ieder worden toegekend met een eigen indicatie.
- Implementatie van manufacturing engineering welke de efficiëntie verhoogt van het engineering proces en de doorlooptijd verlaagt tussen engineering en productie.
- Afwijkingen van het engineering proces moeten worden geëvalueerd om tot een verbetering van het proces te komen. Van de afwijkingen die uit de ad-hoc informatiestromen blijken, moet de oorzaak worden herleid.

De opdrachtomschrijving wordt:

"Ontwikkelen van een Workflow Management Systeem dat in staat is om de geplande en ad-hoc informatiestromen te beheersen, en bijdraagt aan:

- Lagere kosten
- Verhoogde efficiëntie van het engineering proces
- Identieke of kortere doorlooptijd van engineering"

Voor het Workflow Management Systeem (WMS) is een product-georiënteerde structuur noodzakelijk, met gebruikmaking van de huidige geïmplementeerde Schelde System Work Breakdown Structure (SSWBS). De product structuur wordt bepaald met behulp van een Product relatie Matrix, die verticaal systemen en horizontaal system parts bevat. De relaties van de system parts tot met systemen worden gedefinieerd door functionele en interface- relaties. De afhankelijkheid tussen twee system parts is gedefinieerd bij de relatie van beide system parts tot een gelijk systeem. De matrix wordt gebruikt voor de volgende aspecten:

- In de eerste plaats wordt de engineering workflow gedefinieerd als alle toegepaste transformaties op een relatie. De relatiewaarde is de beschrijving van een relatie in een engineering document met product parameters. De inhoud van technische documenten en activiteiten wordt bepaald met gebruik van sub- en aspect systemen van de Product Relatie Matrix. Het sub- of aspect-systeem bevat een verzameling van relatiewaarden.
- In de tweede plaats worden de relatiewaarden toegewezen met een betrouwbaarheidsindiciatie. De relatiewaarde verandert bij elke stap van het engineeringproces. Van een globale beschrijving in de contractspecificatie in een detail specificatie voor het bestellen tot een 3D CAD-model voor detail engineering. De betrouwbaarheid van elke relatiewaarde zal worden vastgesteld van 'Onbewerkt' tot 'Goedgekeurd'.
- In de derde plaats ondersteunt het Workflow Management Systeem het wijzigen van het ontwerp. De gevolgen van een wijziging van het ontwerp kunnen worden geanalyseerd met gebruik van de Product Relatie Matrix. De oplossing kan worden vastgesteld in een afrondende vergadering.

Bovenstaande procedures worden ondersteund door het toewijzen van taken en het verzenden van notificaties aan de deelnemers aan het project. Het adresseren van informatie wordt uitgevoerd met behulp van de link tussen de relaties en de engineeringactiviteiten.

Het Workflow Management Systeem draagt bij aan:

- Een hogere efficiëntie van het engineeringproces. Het product, gedefinieerd in de product Relatie Matrix, is in staat om de informatie te adresseren aan de deelnemer van het project. Verder wordt de deelnemer ondersteund met een dashboard waarin de beschikbare technische informatie en taken die moeten worden uitgevoerd, worden weergegeven. Het Workflow Management Systeem ondersteunt de procedure voor ontwerpwijzigingen.
- De kosten voor het ontwerpproces zullen lager worden nadat de investering voor de opzet en invoering van het Workflow Management Systeem is terugverdiend. De terugverdientijd zal

ongeveer twee tot drie jaar bedragen. Dit kan alleen bereikt worden met een gecombineerde ontwikkeling en invoering van WMS met de nieuwe ERP- software ' IFS ‛.

- De doorlooptijd van engineering kan verminderen. Ten eerste verlaagt de snelle adressering van informatie de doorlooptijd van engineering. Ten tweede kan het Workflow Management System resulteren in minder benodigde tijd aan aanpassingen in het ontwerp. Ten derde kan de overdracht van wijzigingen aan het engineering proces sneller gaan. De implementatie van betrouwbaarheid indicaties in het 3D CAD-model maakt het mogelijk om het 3D CAD-model te gebruiken voor de communicatie van engineering informatie.

List of abbreviations

BE	Basic Engineering
DE	Detail Engineering
DSG	Damen Shipyards Group
DSGo	Damen Shipyards Gorinchem
DSM	Design Structure Matrix
DSNS	Damen Schelde Naval Shipbuilding
EAL	Engineering Activity List
EDC	Effective Date of Contract
EVM	Earned Value Management
FAT	Factory Acceptance Test
HAT	Harbor Acceptance Test
JSS	Joint Support Ship
LCF	Air Defence and Command Frigate (Lucht Commando Fregatten)
ME	Manufacturing Engineering
NCN	Non Conformity Notes
OPV	Offshore Patrol Vessels
PDL	Process Description Language
PDM	Product Data Management
PIMS	Product Improvement Management System
PM	Project Manager
PRM	Product Relations Matrix
RFQ	Request for Quotation
RNN	Royal Netherlands Navy
SAT	Sea Acceptance Test
SSWBS	Schelde System Work Breakdown Structure
STALK	Standaard Ladekast
SWBS	System Work Breakdown Structure
TL	Team Leader
TOT	Transfer Of Technology
VDDS	Vendor Data Delivery Schedule
WMS	Workflow Management System

Contents

1 Introduction

Damen Schelde Naval Shipbuilding (DSNS) is delivering naval vessels to customers all over the world. DSNS is well-known for its high quality and delivering on time. The market of DSNS is shifting as result of the budget cuts of the Royal Netherlands Navy and the growing defense budget of the Asian countries. The new market demands competitive prices, local shipbuilding and transfer of technology. The logistic management of production as well the management of the engineering process will become a condition for project success.
The focus within the engineering process has been always on product quality. The focus has resulted in the high quality of the naval vessels, which is confirmed by the customers. The efficiency of the engineering process is attracting more attention, as consequence of the decrease of engineering budget.

The question which is the basic for this thesis is: How is the current Workflow Management System and does the current system complies with current project requirements: delivering on time, high quality, and lowest cost?

This report has the following structure. Chapter two describes the project and engineering process of DSNS. The next chapter is to become to an understanding of the engineering process of DSNS according the Delft Systems Approach. In chapter four the problem statement is described, which is based on the analysis. Chapter five contains the definition of the Workflow Management System (WMS), where after in chapter six the implementation of the WMS is described. The financial analysis is incorporated in chapter seven. Final chapter contains the conclusions and recommendations for the implementation.

2 Damen Schelde Naval Shipbuilding

With an annual turnover of 1.3 billion Euros and more than 6.000 employees Damen Shipyards Group (DSG) acquired a leading position in shipbuilding and repair worldwide. With 35 yards worldwide DSG annually delivers 120 to 150 vessels for different purposes (Figure 1). The vessels are based on a unique standardized design concept or will be custom designed. Keeping 150 hulls on stock will ensure a very short delivery time.

Damen Schelde Naval Shipbuilding (DSNS) was founded in 1875, at that time called the NV Koninklijke Maatschappij de Schelde. The most well-known name of the company is 'Koninklijke Schelde Groep'. In 1971 the company becomes a state owned company and in 2000 it becomes a member of Damen Shipyards Group. Firstly, in this chapter an explanation of the products and markets of DSNS is given. Secondly, a description of the engineering process is given. Finally, known issues of the engineering process are listed.

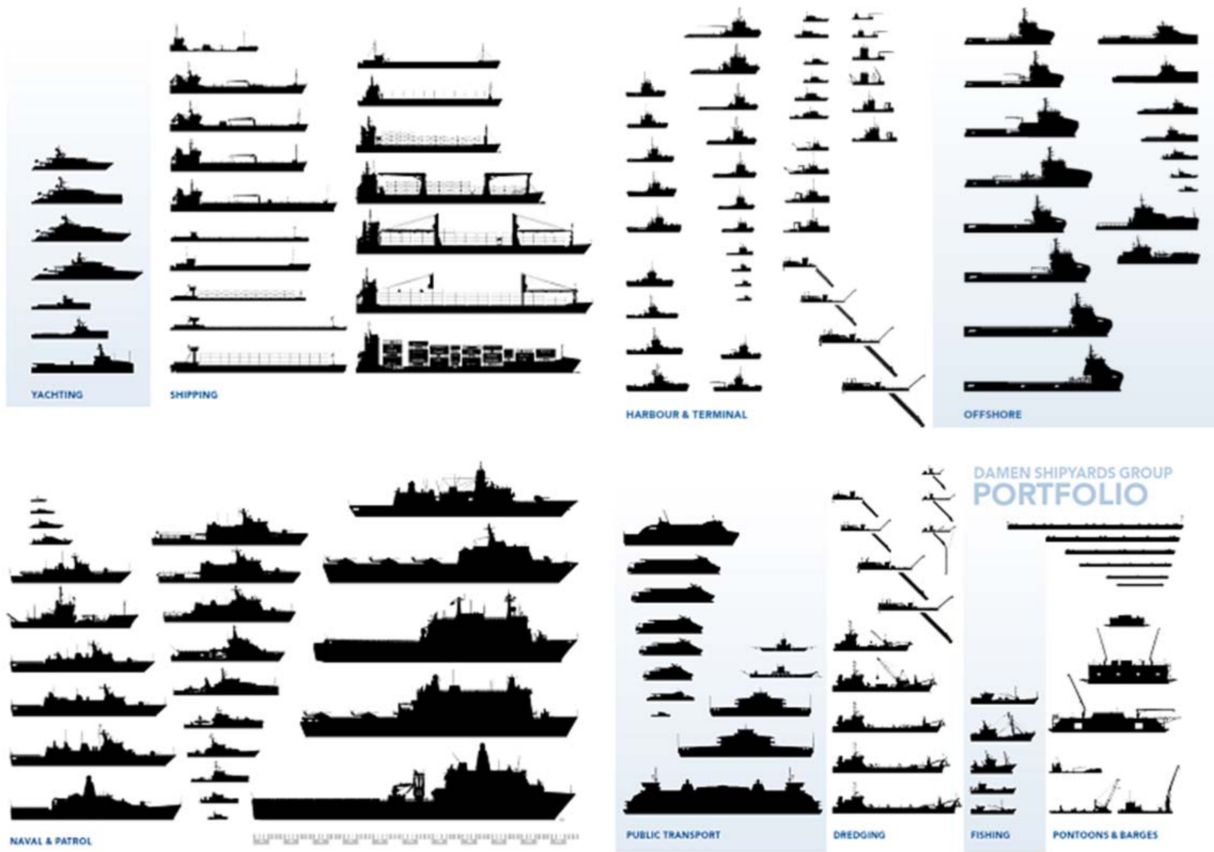


Figure 1 Portfolio Damen Shipyards Group

2.1 Products and Market

The focus of DSNS has always been on the naval vessels. Over time, also civil vessels are built by DSNS, such as chemical tankers, catamarans, and ferries. Since the takeover by the Damen Shipyards Group, DSNS is mainly focusing on the naval market. The civil market is part of the portfolio of Damen Shipyards Gorinchem (DSGo). This agreement will not exclude any civil work for DSNS. DSGo is using capacity and expertise of DSNS for civil vessels and 'light gray vessels'. 'Light gray vessels' are supporting the navy, but are in general not equipped with weapons. Examples are submarine rescue vessels and coastguard type vessels.

Naval vessels as service vessel

The naval vessels of DSNS can be divided in two product groups (Figure 1 and 2):

- Combatants and Offshore Patrol Vessels (OPV)
- Amphibious Support Ships & Naval Auxiliaries

Combatants are vessels which are being able to take part in an armed conflict. According their specific purpose they are equipped with different weapons and surveillance systems. The "Lucht Commando Fregatten" (LCF) of the RNN are equipped with an air radar and combat system for the interception of missiles. An OPV is designed to operate in coastal waters and is able to perform combat operations. The Holland Class of the RNN is able to operate in coastal waters everywhere in the world.

The Amphibious Support Ships are provided with a large bay dock which can be used for landings crafts and are able to deploy and support ground troops. These vessels are usually also fitted with a larger helicopter deck. The Naval Auxiliaries are able to support the naval fleet during missions and operations. The Joint Support Ship (JSS) 'Karel Doornman' is currently under construction. Data and examples within this research are partly based on the JSS project. A product description of the JSS is included in 0.

Figure 1 Combatant

Figure 2 Amphibious Support Ship

Naval vessels can be classified as service vessels. The specific characteristic of service vessels are (Oers, 2011):

- Extreme integration of operational functions (like air defense, surveillance, vessel support) and platform functions (providing accommodation, survivability, and mobility) (Coenen, 2008).
- Operational functions are customizable by client.
- One-off's or small series.
- Many systems subcontracted.

Each vessel is able to perform the defined platform functions. Common functions for transport vessels and service vessels are accommodation, survivability and mobility. In addition to platform functions service vessels have also operational functions. The operational functions can be air defense, supporting landings of ground troops, et cetera. These operational functions are interrelated with the platform functions. The possible attacks on naval vessels will influence the requirements for survivability of a naval vessel. The noise emission of the power train, which is part of platform function mobility, has to be limited to decrease the underwater noise (operational function).

The operational functions of naval vessels are defined by the client. The mission profile of naval vessels determines the operational functions which have to be performed by the naval vessel. The Joint Support Ship of the RNN has to be able to supply other naval vessels, but should also be able to transport an amount of vehicles and helicopters. The required customization of the naval vessel results in a one-off design and production, or probably a small series of about four vessels. DSNS has designed a standardized combatant, the SIGMA, which is customizable by client. The development of the SIGMA is performed by the Standaard Ladekast (STALK) project (see Appendix B).

Market change

DSNS participates in the naval market with (semi-)governmental authorities as customers. The market is determined by the defense budgets of countries, which are politically directed. DSNS was the preferred supplier of the Royal Netherlands Navy (RNN) and therefore most turnover came from the RNN. These projects are characterized with a high influence of the RNN on the product design, engineering process, used materials, suppliers et cetera.

The budget cut of the RNN, corresponding to other European countries, is the opposite of the defense budget growth of Asian countries (The International Institute for Strategic Studies, 2012). The defense budget of Asian countries is increasing and the budget plans are containing several new building plans for naval vessels.

The new market demands competitive prices. The competition is high due to entering of several European shipyards but also Asian shipyards. Part of the strategy is building the hull or complete vessel on the Damen Shipyard Galatz yard in Romania. The detailed engineering is (partly) subcontracted to MEGA, a Damen Owned Engineering office in Galatz. The new requirements of (potential) customers of local shipbuilding and transfer of technology will change the shipbuilding strategy in the next years.

Transfer of Technology

New customers have limited experiences with design and production of complex naval vessels. However these governments want to develop and improve at the same time the local shipbuilding industry. The new shipbuilding plans will be understood as an opportunity to setup a shipbuilding industry, which is able to develop and build their own naval vessels in the next future. To achieve this goal the Request For Quotations (RFQ) are enlarged with the requirement of local content and the Transfer of Technology (TOT).

DSNS has investigated the possibilities of local shipbuilding of parts of the vessel, which has resulted in the modular shipbuilding strategy (Figure 3). The vessel is divided in several modules, which can be built separately at different locations. A strategy is developed to handle involvement of the less experienced local shipyards, to build a part of the naval vessel. This strategy is further explained in Appendix B.

Transfer of Technology can be part of the local shipbuilding strategy. TOT is used to educate the local employees to achieve the Damen quality requirements imposed to the local shipyard. The education of engineers, managers and other functions can also be part of the contract.

Figure 3 SIGMA combatant displayed in modules

2.2 Engineering process of the naval vessels

The building and delivering of a new vessel will be performed by a set of activities (Figure 4), starting with contract acquisition until the end of the warranty period of the delivered naval vessel. DSNS usually defines the project as the period between Effective Date of Contract (EDC) until the end of the warranty period of the naval vessel. This period is usually three or four years for the first vessel, and year later for every sister vessel. The definition of the project period excludes the contract acquisition. The contract acquisition can be varying from one to three years.

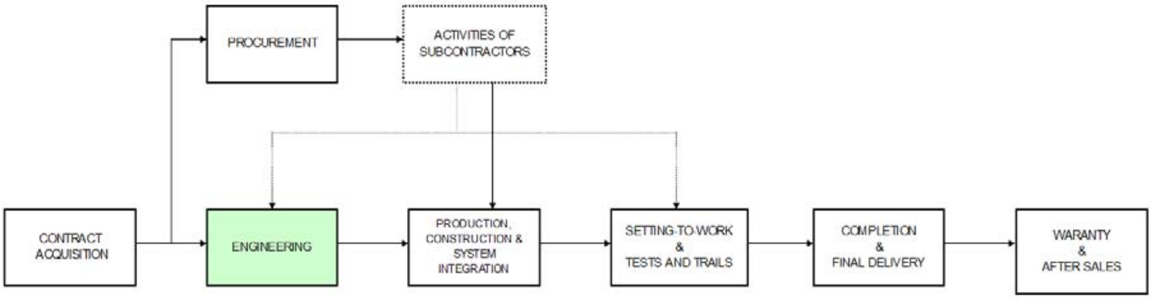


Figure 4 Project activities of a new building design (Damen Schelde Naval Shipbuilding, 2012, p. 9)

Last year the engineering department has drawn up a policy plan about "engineering for the coming years", in accordance with the policy of DSNS. The following objectives are listed in the Engineering policy plan 2012:

- Product standardization
- Worldwide shipbuilding on local shipyards
- Modular building
- System integration as core competence
- Integration of manufacturing information into the engineering information though 'Manufacturing Engineering'
- Improving quality of engineering information in aspect to reliability.
- Integration and expanding of product lifecycle services

System engineering approach

The usual design approach within the shipbuilding industry is system engineering (Coenen, 2008). The system engineering approach is modeled with a V-model. A V-model, suitable for the shipbuilding industry, is displayed in Figure 5.

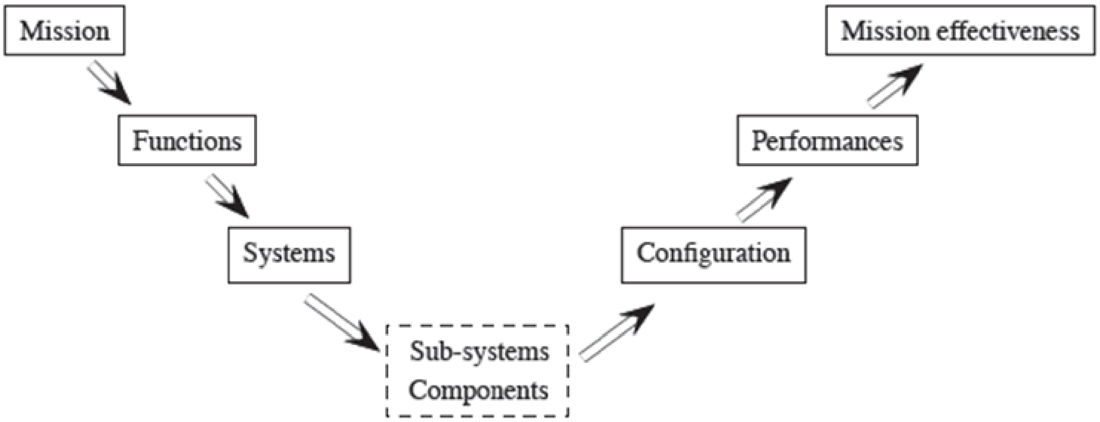


Figure 5 The V-model of the shipbuilding industry (Coenen, 2008, p. 4)

The product design starts with the definition of the mission of the product. In case of naval vessels, the missions which have to be fulfilled and the spectrum of violence. The mission will be translated in a function description of the vessel. The function description describes which functions are necessary to fulfill the mission of the vessel. The functions are configured into necessary systems and subsystems, which will be worked out up to component level.

The systems and components will be transformed into a vessel configuration: the integration of systems. The measuring of the performance is the verification of the functions which answer the question: 'Is the design right'. The mission effectiveness is the validation of the mission: 'Is it the right design'.

Engineering steps

The output of the contract acquisition is amongst others a contract specification consisting of a functional description of the vessel. Besides the functional description also some system- and component definitions are part of the contract specification.

The detailing of the systems up to component level is performed during the Basic Engineering (BE). The integration or configuration of the product is started in the Basic Engineering phase and worked out in detail during the Detail Engineering (DE) phase. The division between Basic and Detail Engineering becomes vaguer with the increasing integration of both engineering tasks in one software package. The Basic and Detail Engineering will be performed partly parallel, which can be seen in a typical planning overview in Figure 6.

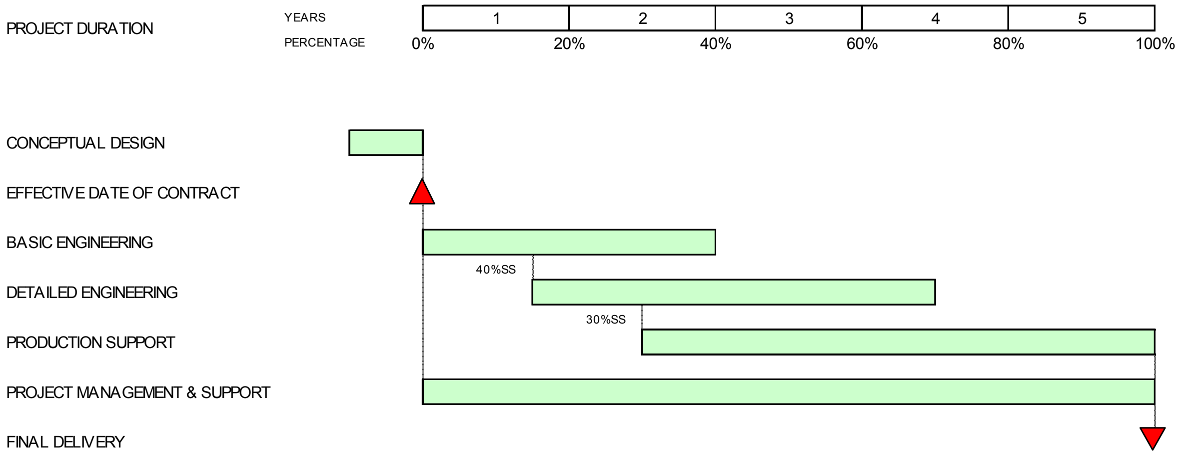


Figure 6 Typical planning of Engineering (Damen Schelde Naval Shipbuilding, 2012)

Basic and Detail Engineering

Basic Engineering is the first phase of the Engineering process which will start with EDC. The Basic Engineering defines the systems of the vessel, which result in system design documents. It's the transformation of the functional requirements of the contract specifications into a system description. The system documents will be used for three purposes.

First, the documentation is made for approval by the class society. The class society (defined in the contract specifications) approves the system design of the vessel according the class requirements and international safety requirements. Besides the approval by class the engineering documents will in general also be approved by the customer. This approval contains the verification of the design.

Secondly the system documents will be used to make the technical specification of the components. The technical specifications will be made according the functional requirements of the contract specifications and the requirements that arise during the system design. The technical specifications will be input for the procurement and selection of equipment.

Finally, the system documents are used to make the configuration of the vessel. This third purpose contains the trade-off between the technical specifications documents of components and the system design documents. Both document types are part of the vessel configuration description and are therefore highly interrelated. The configuration of the vessel is on lower detail performed by Basic Engineering and detailed during Detail Engineering.

Basic Engineering can be characterized as concurrent engineering: the engineering activities are performed in parallel to shorten the lead time of engineering. Figure 7 shows an enumeration of the involved disciplines which will be performed parallel.

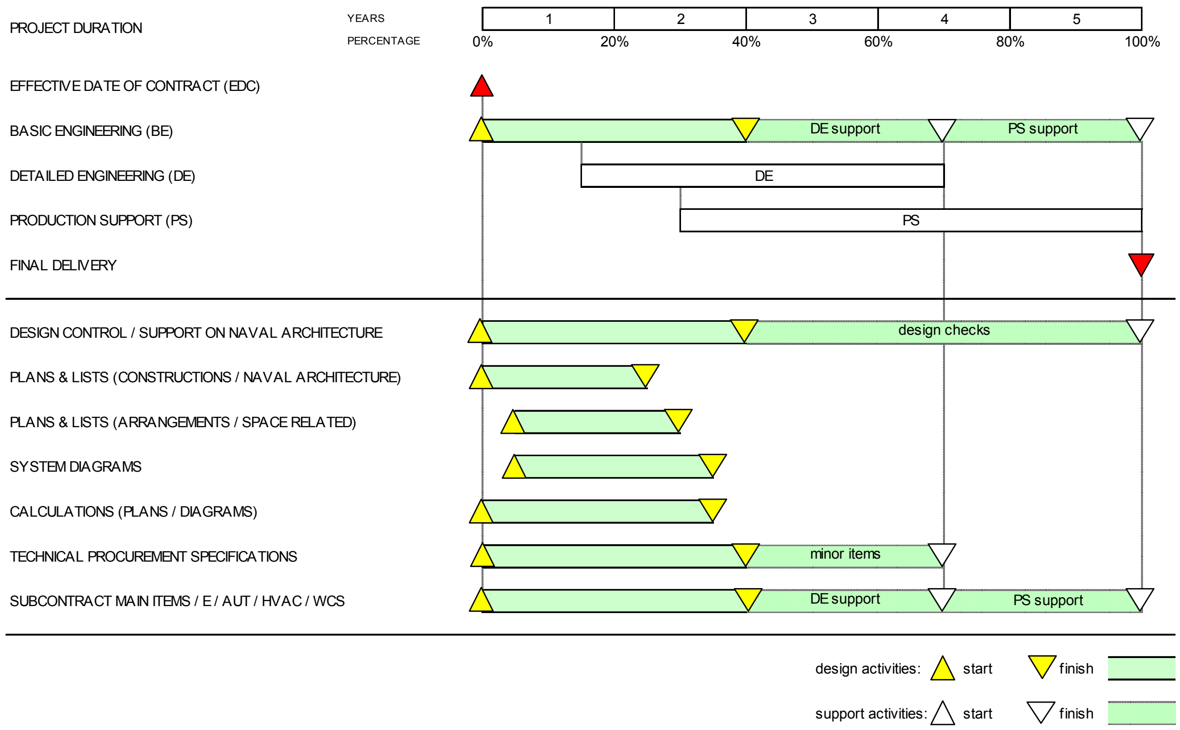


Figure 7 Typical planning of Basic Engineering (Damen Schelde Naval Shipbuilding, 2012)

The purpose of Detail Engineering is the delivery of production information to the shipyard, in particular the bill of manufacturing. The bill of materials is usually already released during Basic Engineering. This is performed with use of the system documents and arrangements (low detail configuration). The product configuration will be detailed with 3D CAD software, resulting in a 3D CAD product model. The essential step during detail engineering is adding of production information. This information is dependent on shipyard capabilities and will be delivered on 2D production drawings. These drawings are extracted from the 3D CAD model.

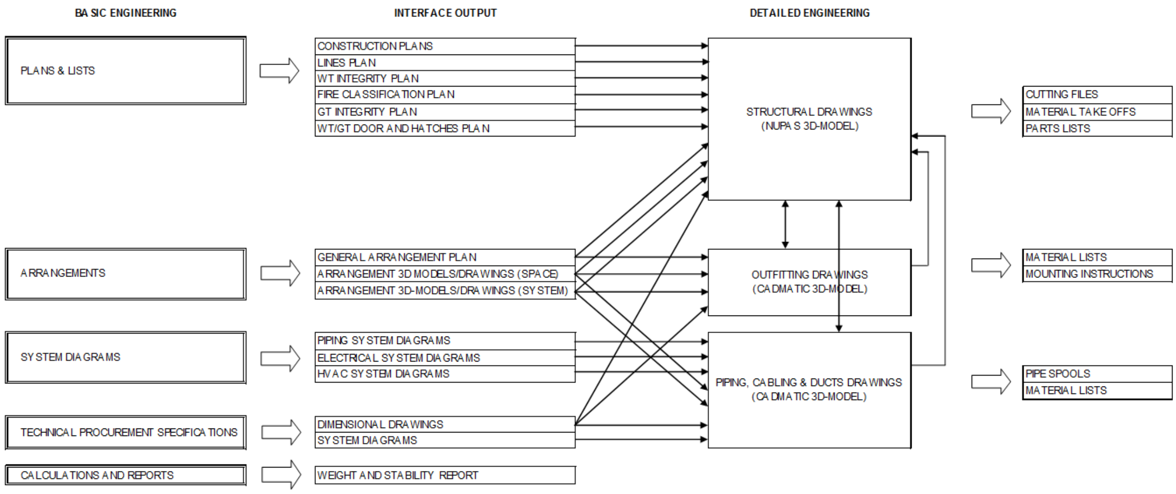


Figure 8 The information flows between Basic and Detail Engineering (Damen Schelde Naval Shipbuilding, 2012)

Production support

During the shipbuilding process engineering is giving technical support to the shipyard which will be performed by a modification team. The modification team will answer the technical questions (Non Conformity Notes) from the shipyard. Modifications are caused by shipyard, class society, client or changing component specifications. The modifications will be applied on the 3D product model and revised 2D production drawings are released to the shipyard.

Subcontracting of system design and manufacturing

The shipbuilding industry in Europe usually subcontracts parts or even complete systems of the vessel to other supplier. Typically the following systems are subcontracted: Heating, Ventilation and Air-conditioning, Electrical, automation, Accommodation and combatant systems. DSNS acts as system integrator and supplier of the vessel platform (hull) for all systems. The procurement value of subcontractors and suppliers of a project can be up to 80 percent of the total project value. Beside the main subcontractors as mentioned more than 50 suppliers are involved in delivering of equipment.

The subcontracting of systems is usually split into a subcontractor performing design, delivery and commissioning of the system and other (local) subcontractor performing the installing onboard.

The subcontracting of system design and manufacturing requires a high level of communication between the involved participants. The design process of the subcontracted systems is highly interrelated with the system design process of DSNS. The system integration requires an integration of the subcontractors in the design process of DSNS. The integration can be done with the availability of employees from subcontractors at the DSNS office or by e.g. frequent organization of video conferences, integration meetings, sharing 3D model etc. Management of the relationship between the subcontractor activities and the activities of DSNS is the responsibility of the subcontract manager. In practice DSNS not only act as main contractor, but also as subcontractor for other companies within the Damen Shipyards Group.

Appliance of outsourcing in current projects
EGS/RGS: Two submarine rescue vessels (83 and 93 meters) Damen Shipyards Gorinchem (DSGo) was winner for a contract for delivery of two rescue vessels to a naval related customer. DSGo as main contractor is performing the management, procurement and expediting and has subcontracted the Engineering to DSNS. Next DSNS has subcontract a part of Detail Engineering to MEGA in Romania. **PKR: Two combatants for Indonesia (105 meters)** PKR is becoming the first project which is making use of the modular shipbuilding strategy. The main contractor is DSNS which subcontracts a part of the Detail Engineering to MEGA. The Production will be done on three shipyards. Planning is to build the power plant in Damen Shipyards Galatz, the superstructure forward module containing the combat system in Vlissingen and the remaining modules in Surabaya. The modules will be merged in Surabaya. The management of the shipbuilding process in Surabaya is performed by DSNS. Shipyard Galatz manages the shipbuilding process itself. **Request for Quotation for Logistic Support Vessel** A new Logistic Support Vessel was quoted by DSNS. The main contractor which is also performing the procurement of the project will be an external shipyard. DSNS was asked to perform Engineering and Production. The Production would be subcontracted to Damen Shipyards Galatz.

2.2.1 Project team structure

For every project a project team is setup which is responsible for the project execution. The engineering project team has the following structure (Figure 9):

- Every project has a General Project Manager and several Project Managers (PM) for the different disciplines as engineering, procurement et cetera. The Project Manager approves the engineering documentation, after check of this document by the Team Leader.
- One level lower in the project team organization consist of several Team Leaders (TL). The TL is responsible for several systems in case of Basic Engineering, or responsible for a part of the naval vessel in case of Detail Engineering. The TL is assigned with the following tasks (Damen Schelde Naval Shipbuilding, 2012):
    - Collection, distribution and updating of the required engineering information.

- Monitoring progress, budget and quality of his team.
- Introduce specific procedures, work methods, tools which are necessary for the project.

The check of the engineering documents by the TL has to secure the quality of engineering information.

- Every TL is leading a group of engineers. In case of Detail Engineering the group of engineers is multidisciplinary.

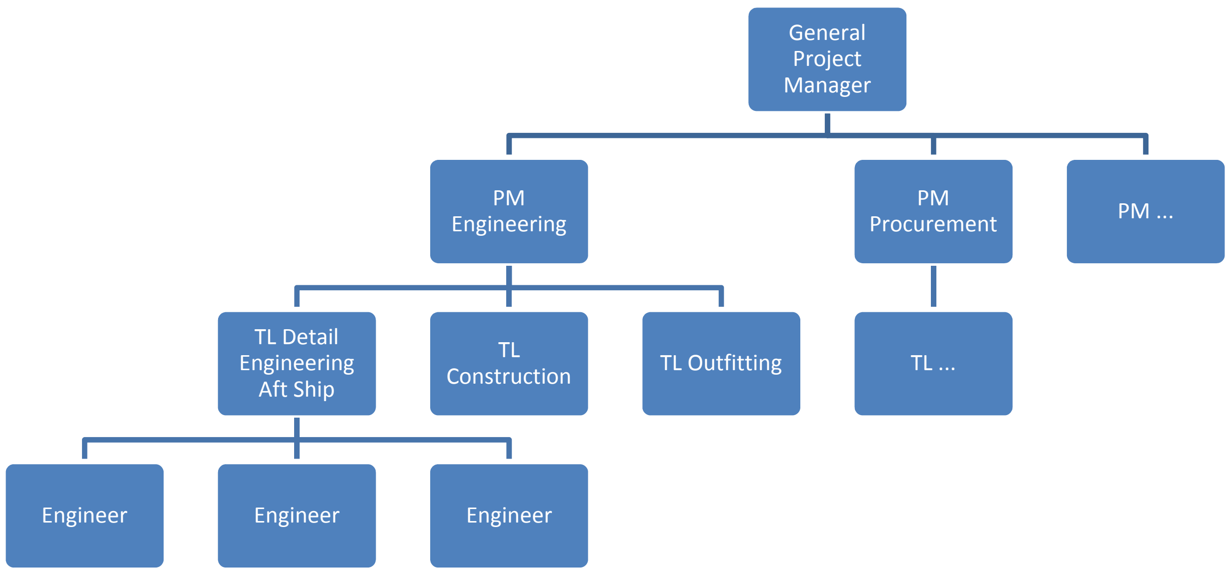


Figure 9 Project team structure

2.3 Engineering management

The engineering management is based on cost, time and quality. Firstly, an overview of the Product Data Management is given. Secondly, the measurement of the time and cost aspect of the engineering process which is performed with Earned Value Management. Thirdly, quality control is performed by design reviews, document validation and product tests.

Product Data Management

DSNS is using 'Teamcenter' for Product Data Management (PDM). Teamcenter is the database of all engineering documents, system parts and items (Figure 10). The data is directly registered in Teamcenter or received by Teamcenter from the several used engineering software. All engineering data is registered according the Product Structure. Teamcenter is not able to analyze the content of an engineering document. It only stores the engineering document as file in accordance with the Work Breakdown Structure.

Teamcenter is implemented for document quality control by assigning validation tasks to the Team Leader and Engineering Project Manager. Also the validation process of revised documents is managed by Teamcenter.

On the other side Teamcenter is also sending engineering data to other software, 3D CAD software. Several data viewers make it possible to view the engineering data, without editing possibilities. Further information can be found in 0.

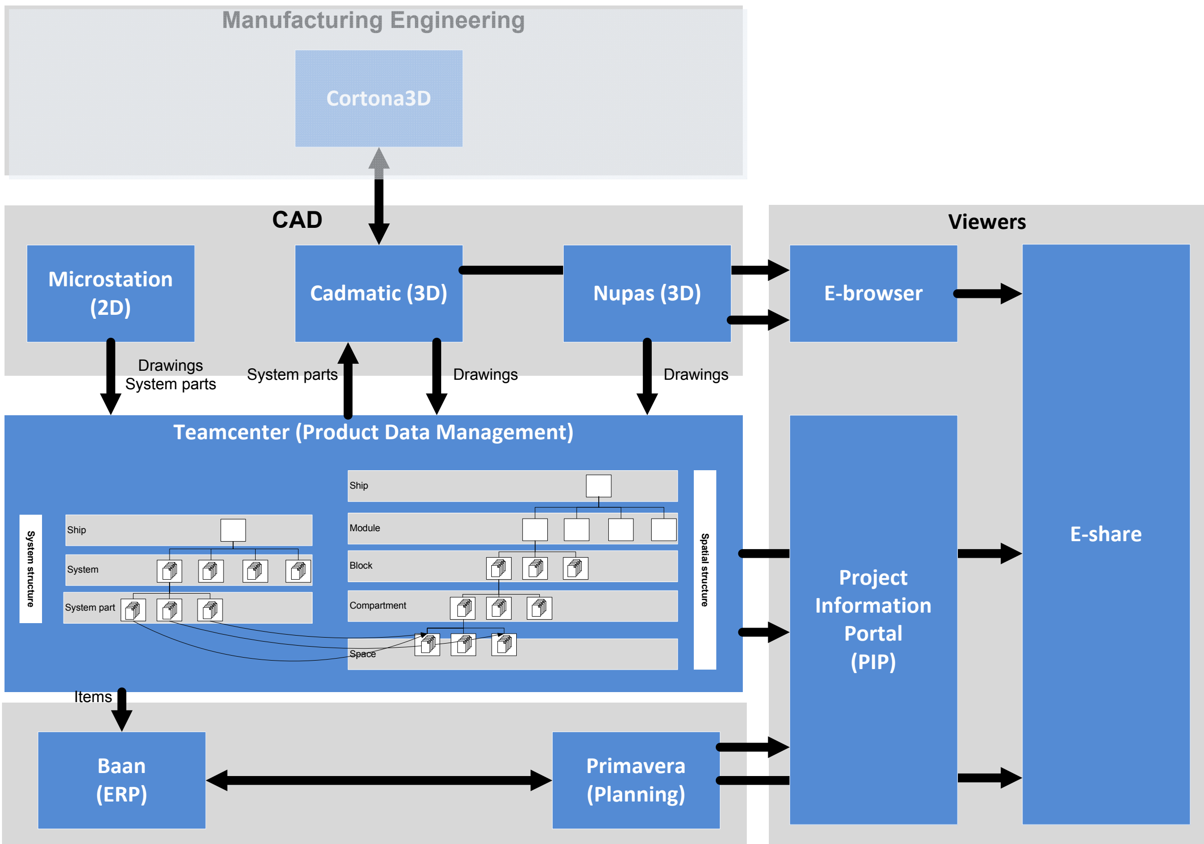


Figure 10 Data structure of DSNS.

Earned Value Management

Maintaining of the planning is done with Earned Value Management (EVM) (Damen Schelde Naval Shipbuilding, 2012). The methodology measures the planned value, earned value and actual costs:

- The planned value is coming from the initial planning.

- The earned value is calculated with use of the progress of engineering activities. The progress measurement is different for engineering and production.
  - The engineering progress will be determined by Team Leaders. With use of a progress table the progress of every activity will be estimated. The progress percentage has as starting point that all engineering information related to the engineering activity has the same progress. This method is also applied for the subcontractors.
  - Production is doing some research for new methods to achieve a reliable progress measurement. At the moment the progress is manual determined by an employee. The determination is subjective and dependent on the employee. When two independent persons doing the same progress review, the outcome will be different. Therefore a new method will be developed, with use of RFID on components. With this method the progress is based on the availability of components in a certain space. Limitation of RFID is that it cannot be used to measure the progress of painting, welding et cetera.

With physical progress and planned hours (or budget hours) the earned value can be calculated.

- The actual costs are based on the booked engineering hours in the ERP-system and transferred to the planning system.

With plotting the three indicators, the actual performance will be showed (Figure 11). The figure gives an overview of the current situation and the performance in the past. EVM is only doing a rough measurement of the performance of the project process. Firstly, the reasons which contribute to delay or inefficiency are still unanswered by EVM. Secondly, the rough measurement of the project progress results in the loss of small engineering issues. These small issues can grow out to a large disruption of the engineering process. Finally, it is not allowed to decrease the engineering progress during the engineering project. DSNS uses the method only for hours.

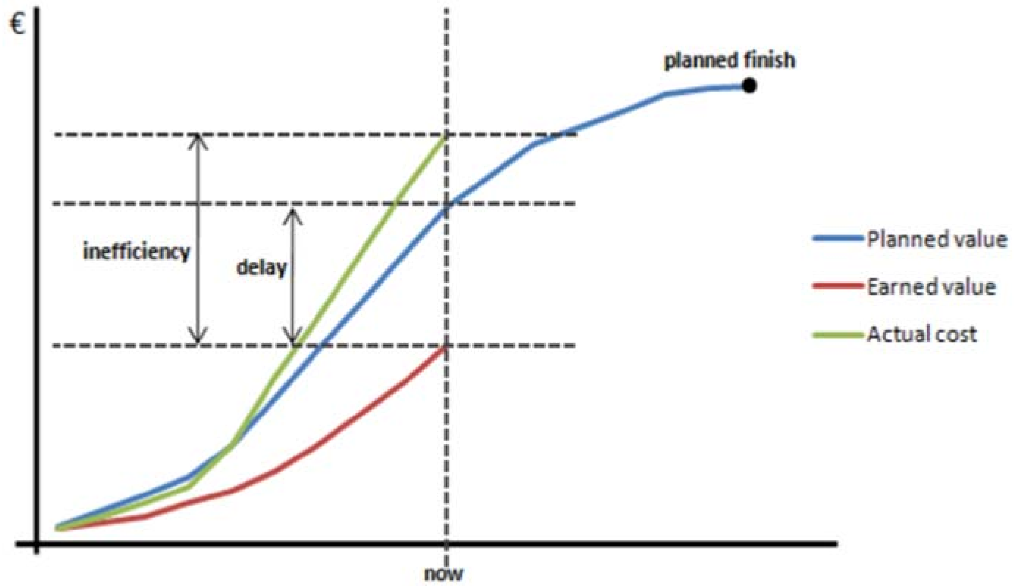


Figure 11 Earned Value Management (source: manual planning creation)

Validation

Part of the systems engineering approach is the verification and validation of the product design. The validation and verification is performed by three design reviews, document validations and product verification.

Firstly, the three design reviews during engineering: One at the start of Basic Engineering, the second with the start of Detail Engineering and the last, which is also the validation, will be performed after commissioning of the naval vessel.

Secondly, the release process of every engineering document contains a quality control. Some major engineering documents are also subject to external approval by the class society and or customer. The four states of an engineering document are (Figure 12): Working, Checked, Approved and Released. The engineering document is checked by the Team Leader and there after approved by the Engineering Project Manager. The release of an engineering document is in general immediately after approval.

These four validation states are applied to every engineering document, also in case of a document revision. A document revision will take place if an engineering document changes after approval. The validation state 'Approved' does not imply that the content is completely final information.

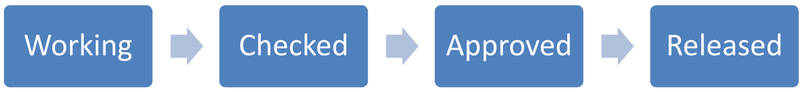


Figure 12 the validation states of an engineering document.

Thirdly, the product verification is arranged by the Factory Acceptance Tests (FAT), Harbor Acceptance Tests (HAT) and the Sea Acceptance Test (SAT). These tests are milestones for the approval of components (FAT) systems (HAT) and final the performance of the vessel (SAT).

2.4 Known issues in current engineering process

In the engineering process there are some known issues which influence the performance of the engineering process. The issues are experienced or reflected in conversations with people.

Communication between project participants

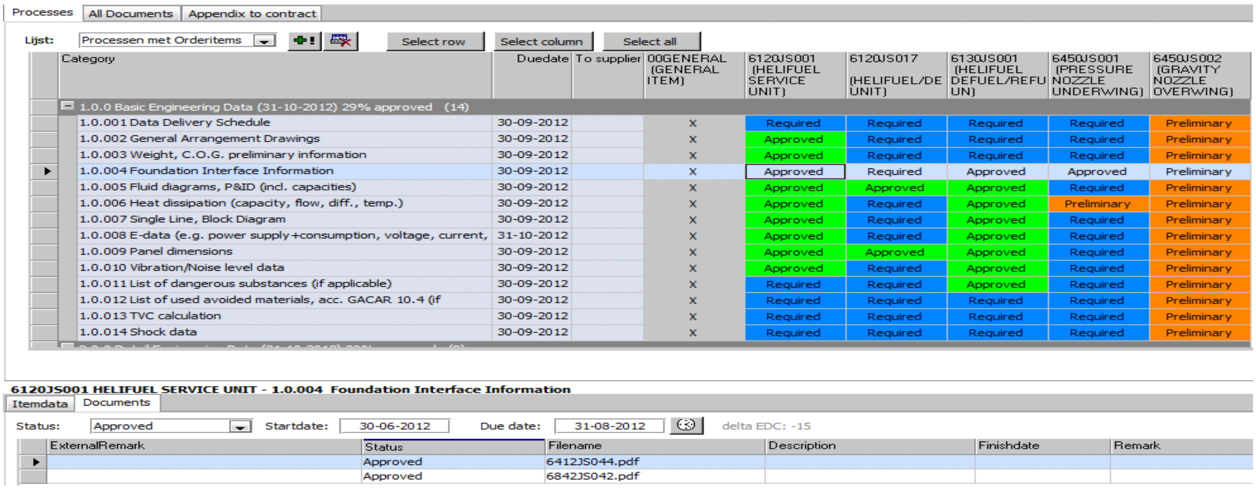
Beside the formal communication, an extensive part is informal communication: People are walking to each other with questions resulting in short communication lines. The risk of informal communication is not reaching individual engineers, which is also reflected by engineers.

The informal communication may result in a wrong estimate of the project progress and issues are not official reported to the project management. The formal communication consists of the release of product(ion) information and minutes of project meetings. The project meetings are used to discuss the project progress and the critical systems or components.

Missing engineering information

A problem during the engineering process is the missing of engineering information. This will delay the engineering process and can result in engineering changes through the use of assumptions instead of finalized engineering information. The missing of engineering information has two reasons:

- Firstly, caused by the delay of receiving information from subcontractors and suppliers. DSNS acts as system integrator and is therefore dependent of external information. During the project of the Joint Support Ship the impact of missing information of suppliers and subcontractors is revealed. Delay of component information causes delay into the entire engineering process. DSNS wants to improve the availability of component information by the introduction of the Vendor Data Delivery Schedule (VDDS) tool (Figure 13). This tool makes the requested information known to the subcontractor or supplier and can be used also to control the progress of information supply. Although this problem occurs less with internal information, also internal information is missed by project participants for another reason.



Processes | All Documents | Appendix to contract

Lijst: Processen met Orderitems | Select row | Select column | Select all

Category	Duedate	To supplier	00GENERAL (GENERAL ITEM)	6120JS001 (HELIFUEL SERVICE UNIT)	6120JS017 (HELIFUEL/DE UNIT)	6130JS001 (HELIFUEL DEFUEL/REFU UN)	6450JS001 (PRESSURE NOZZLE UNDERWING)	6450JS002 (GRAVITY NOZZLE OVERWING)
1.0.0 Basic Engineering Data (31-10-2012) 29% approved (14)								
1.0.001 Data Delivery Schedule	30-09-2012		X	Required	Required	Required	Required	Preliminary
1.0.002 General Arrangement Drawings	30-09-2012		X	Approved	Required	Required	Required	Preliminary
1.0.003 Weight, C.O.G. preliminary information	30-09-2012		X	Approved	Required	Required	Required	Preliminary
1.0.004 Foundation Interface Information	30-09-2012		X	Approved	Required	Approved	Approved	Preliminary
1.0.005 Fluid diagrams, P&ID (incl. capacities)	30-09-2012		X	Approved	Approved	Approved	Required	Preliminary
1.0.006 Heat dissipation (capacity, flow, diff., temp.)	30-09-2012		X	Approved	Required	Approved	Preliminary	Preliminary
1.0.007 Single Line, Block Diagram	30-09-2012		X	Approved	Required	Approved	Required	Preliminary
1.0.008 E-data (e.g. power supply+consumption, voltage, current,	31-10-2012		X	Approved	Required	Approved	Required	Preliminary
1.0.009 Panel dimensions	30-09-2012		X	Approved	Approved	Approved	Required	Preliminary
1.0.010 Vibration/Noise level data	30-09-2012		X	Approved	Required	Approved	Required	Preliminary
1.0.011 List of dangerous substances (if applicable)	30-09-2012		X	Required	Required	Approved	Required	Preliminary
1.0.012 List of used avoided materials, acc. GACAR 10.4 (if	30-09-2012		X	Required	Required	Required	Required	Preliminary
1.0.013 TVC calculation	30-09-2012		X	Required	Required	Required	Required	Preliminary
1.0.014 Shock data	30-09-2012		X	Required	Required	Required	Required	Preliminary

6120JS001 HELIFUEL SERVICE UNIT - 1.0.004 Foundation Interface Information

Itemdata | Documents

Status: Approved Startdate: 30-06-2012 Due date: 31-08-2012 delta EDC: -15

ExternalRemark	Status	Filename	Description	Finishdate	Remark
	Approved	6412JS044.pdf			
	Approved	6842JS042.pdf			

Figure 13 the VDDS tool (QE1500.40-1 VVDS-Usermanual.doc)

- Secondly, project participants are not reminded about the availability of new information. This may result in working with out-of-date information by engineers, while other engineers already received updated information. Working with out-of-date information can be reflected in all subsequent activities. The current Product Data Management system doesn't address engineering information to project participants, excepted for the assignment of tasks according the validation of engineering documents.

First time right

The objective of 'first-time-right' for engineering documents is established by the engineering department. The objective is not met, but the reason for that is not known. Some people suggest that the extension of the Basic Engineering will increase the completeness of engineering information. But at the same time the throughput time of the project process cannot be longer with regard to the competition.

It is a fact that Basic and Detail Engineering sheets will be usually two or three times revised before they are ready for production (see 0). An analysis of the JSS project shows that 80 percent of the components are registered before the end of the Basic Engineering (see Appendix D). Taking into account the late contracting of the electrical subcontractor and restricting this analysis to the main components this percentage will be 90 percent. In this manner 10 percent of the main components are registered after the final date of the Basic Engineering period.

Current registration of system parts and engineering document revisions gives no understanding of the source of engineering document revisions and late system part registrations. Some engineering document revisions are part of the general procedure of an engineering process. Late registrations of system parts can be a consequence of changes of the requirements by client.

Engineering change management

People suggest the improvement of the engineering change management. In particular for the management of changes in the 3D CAD model. Subcontractors get access to the 3D CAD model and are able to access the Product Data Management system. This will contribute to quick sharing of engineering information. However the access can also be used for the implementation of engineering changes into the 3D CAD model and the distribution of revised engineering information. The input of the subcontractors is not validated before implementation into the 3D CAD model, which will have consequences for other processes.

The enlargement of the 3D CAD model as communication or validation tool to other project participants is possible with the implementation of an input control.

Release of manufacturing information

The implementation of change management inside the 3D CAD model can contribute to more efficiency of the releasing of bill of manufacturing. Detail Engineering is performing the detailing of the product configuration which results in a 3D CAD model. The released manufacturing information is based on 2D engineering drawings, which are extracted from the 3D CAD model. The conversion process of the 3D CAD model in 2D engineering drawings will cost 25% of the total Detail Engineering hours. These 2D drawings are the input for the job preparation, which is performed by the Project Office. The 3D product model doesn't include the manufacturing instructions.

The Project Office, which is now performing job preparation, wants to integrate the manufacturing instructions in the 3D product model. This will be done by Manufacturing Engineering and has as goal to minimize the conversion steps and keep the link between the 3D CAD model and the manufacturing instructions on the work floor. A possible solution in the next future can be substitution of the 2D drawings on the work floor by 3D animations or 'Lego-like' manuals.

Keeping the information up-to-date is another issue. Changes in the 3D CAD model are not administrated. Therefore the engineering changes can only be manually detected with use of the extracted 2D drawings. The 2D drawings are automatically reflected against the previous release and there after revision 'clouds' are manually assigned to the engineering drawings. People suggest implementing the administration of engineering changes by the 3D CAD model itself. This give also the possibility to use the 3D CAD model as handover of production information to the shipyard and give the responsibility of manufacturing instructions to the shipyard itself.

3 Analysis of the Engineering process

The purpose of this chapter is to come to an understanding of the engineering process of Damen Schelde Naval Shipbuilding. The analysis will be performed according the Delft Systems Approach (Veeke, Ottjes, & Lodewijks, 2008). Firstly, the positioning of the engineering process as part of the total project process will be defined. With the use of the Process Performance model the aspect flows of interest will be modeled.

Secondly, the engineering aspect flow of the Process Performance model is modeled with use of the innovation model. The focus is on the required Workflow Management System. The requirements: high efficiency and low cost results in a list of elements that should be part of the Workflow Management System.

3.1 The engineering process as part of a project

The main process of Damen Schelde Naval Shipbuilding is the transformation of contract specifications into an operational naval vessel. This transformation is project-based. "A project is a set of activities with a defined start point and a defined end state, which pursues a defined goal and uses a defined set of resources." (Slack, Chambers, & Johnston, 2007) In this thesis the start point of the project is defined as the Effective Date of Contract and the end state is the ending of the warranty period of the naval vessel. The warranty period ends one year after handover of the naval vessel. The contract acquisition period is not taken into account.

The project is defined as: 'The transformation of a contract specification into an operational naval vessel'. The three input flows for the transformation function are the contract specifications, the delivered materials and the participating engineers. The output is an operational naval vessel with the associated 'as-built' documentation and the employees who have finished their job in the project process. The focus on the engineering activities in this thesis will restrict the resources to people only.

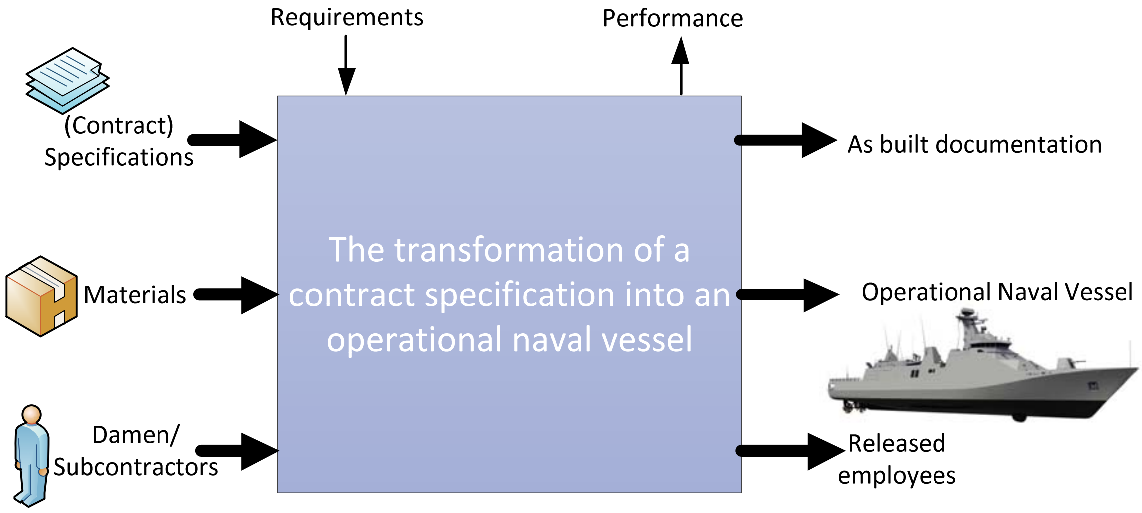


Figure 14 Function model of Damen Schelde Naval Shipbuilding

The requirements and performance of the project process

This thesis focuses on the aspects time and costs. The time aspect is an important factor for Damen Schelde Naval Shipbuilding. Delivery on time besides the well-known quality of the delivered naval vessels is a very important winning factor for new build contracts. Within every project the focus will be delivering on time. DSNS has a competitive delivering time and delivered all vessels so far on time.

The other point is the cost aspect. As seen in chapter two the prices of naval vessels are under pressure requiring more competitive price levels than in the past. The management is looking for methods to lower the cost of shipbuilding. Applied methods are the standardization of the naval vessels and subcontracting of parts to countries with attractive labor costs. The minimization of costs requires focus on efficient processes.

The performance of the project will be based on the profit of the project, and the delivery on time to the customer. The performance of the progress is measured and reported with use of Earned Value Management. EVM is however not being able to detect the issues during project which influence the project performance.

The proper model of the project process

The transformation function of Figure 14 will be further investigated with use of the Process Performance model (ProPer model). The transformation function will be split up in three aspect flows, associated to the three input and output flows of Figure 14.

The first aspect flow is engineering. Engineering is the transformation of the contract specifications into manufacturing information and as-built information. The order is settled with the handover of the as-built information, defining the delivered product. The manufacturing information consists of the bill of materials and manufacturing and is addressed to the second aspect flow.

The second aspect flow is the production of the naval vessel, where the materials are transformed into an operational naval vessel. The progress of production and the Non Conformity Notes (NCN) will be the information flow of production to the engineering aspect flow. Non Conformity Notes are describing issues occurring during production which have to be solved by Engineering. The physical distance between engineering and production will grow with local and modular shipbuilding.

The third aspect flow is the assignment of employees to the two aspect flows engineering and production. The use of local content, e.g. local shipbuilding and the subcontracting of systems will result in a lot of external employees which take part in the project. They will become direct or indirect member of the project team. Direct if they participate into the engineering process, indirect if they deliver engineering information to the project team. DSNS as system integrator has the leading role and has to communicate with all participating project members all over the world. For example a new building project for Indonesia will have participating employees of the local shipyard in Indonesia, employees of Damen Shipyards in Romania, employees of Dutch subcontractors, employees of the Damen Engineering Office in Romania and employees of a subcontractor based in Romania. In general: the amount of external employees but also the geographical division of the employees will make the communication during project processes complex.

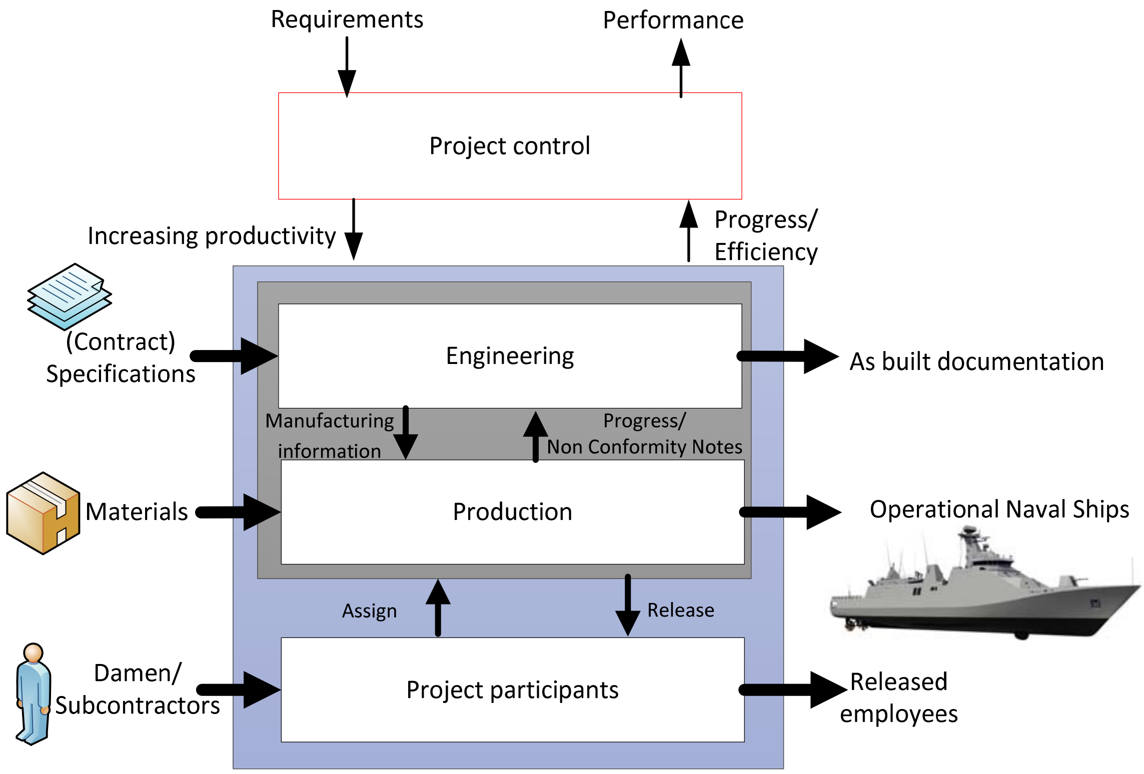


Figure 15 Proper model of a project process

Iterative process

Focusing on the engineering aspect flow points out a growth process, a consequence of the engineer-to-order approach of the project. With project duration of about 5 years for the Joint Support Ship and a timespan of four years between the keel laying and delivering of the vessel to the client, engineering modifications cannot be prevented. During the project client requirements may change and the delivered equipment specifications will change also. The technical development of equipment doesn't stop and some equipment will have their own engineering process in parallel with the engineering process of DSNS. An example is the development of the high tech radar systems, which is often performed in parallel with engineering as well production. A clear statement about the changes during the engineering process can be achieved analyzing the registration date of main equipment for the JSS project. At the start of the production les then 90% of the main equipment is registered and at the end of Basic Engineering 90% is achieved.

The engineering aspect flow is modeled with a part of the innovation model (Veeke, Ottjes, & Lodewijks, 2008). The innovation model contains function and product design. The function design is part of the contract acquisition and is not part of this analysis of the engineering process. The Engineering process is comparable with the product design step of the innovation model. Basically

Engineering consists of two transformation functions. Firstly, the system design and integration, which is derived from the system engineering approach. Secondly, manufacturing engineering which is setting up the production information. Another definition is the design of the product information versus the design of the production information. The two functions are by DSNS organized as Basic and Detail Engineering.

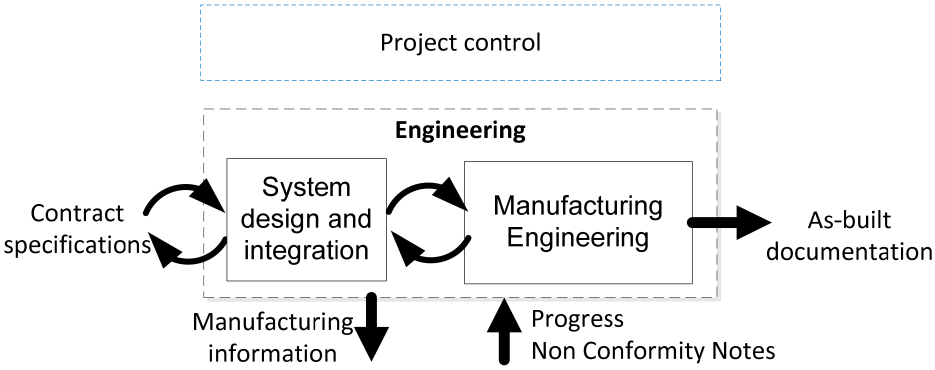


Figure 16 function model of the engineering process

The curved arrows of the innovation model illustrate the iterative character of the engineering process. It is logical that engineering documents will get revised, as consequence of the iterative character. Every engineering sheet will be three to four times revised and released (see 0). The objective to have engineering documents 'First-time-right' is not achieved. However this gives no clear answer regarding the efficiency of the engineering process. The definition of 'First-time-right' has to be applied on final and approved engineering information instead of engineering documents. For example an extra requirement of the customer during the engineering project will enlarge a physical system of the naval vessel. Multiple engineering documents changes and will be classified with revision B. The unchanged part of these engineering document remains 'First-time-right', and the new added information comply with the standard too.

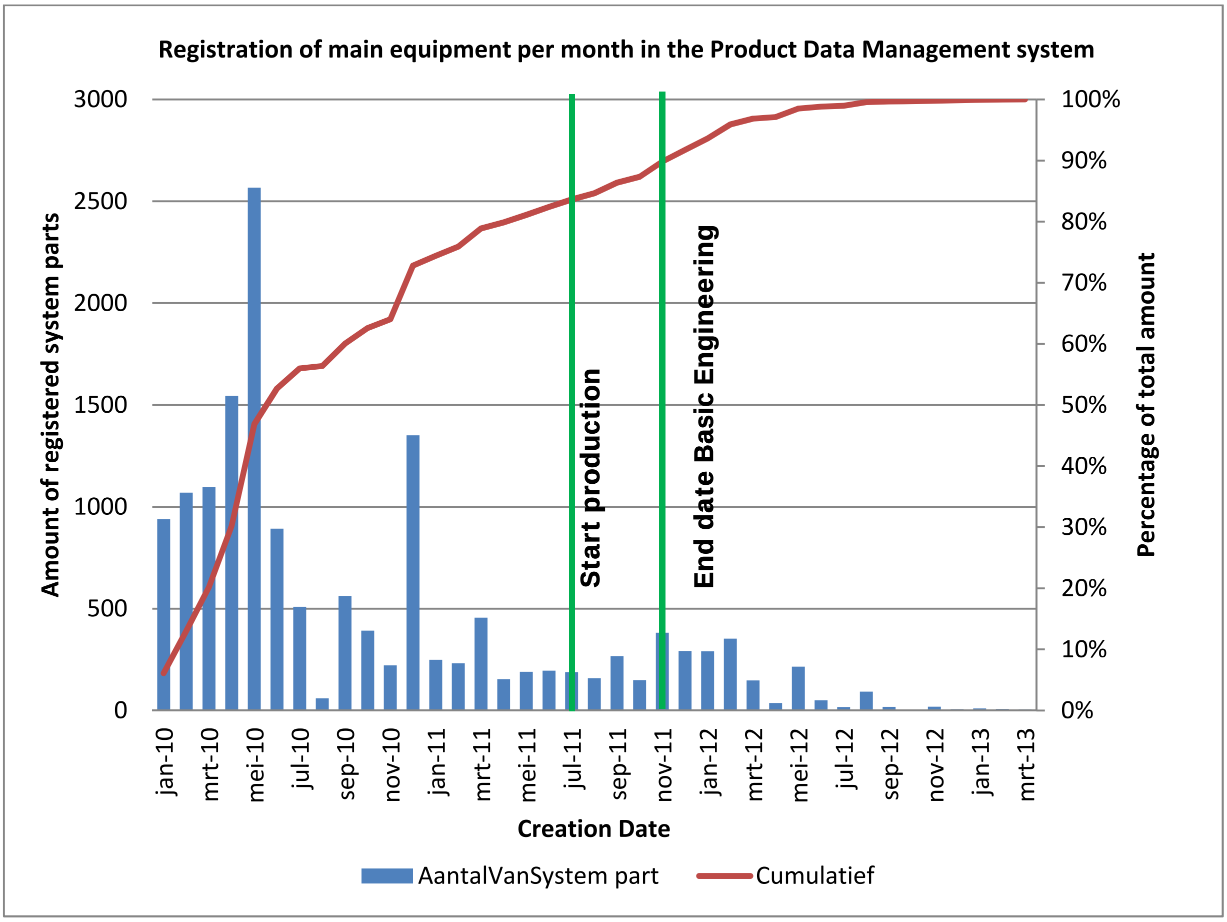


Figure 17 Registration of main equipment per month for the JSS project

3.2 Engineering efficiency

With the focus on the engineering process the requirements of the previous paragraph has to be translated into standards for engineering. The costs of engineering are labor cost. A decrease of the cost of engineering can be achieved with outsourcing to low-wage countries or the decrease of spent engineering hours. This thesis focuses on the decrease of engineering hours with increasing the efficiency of engineering.

DSNS has already implemented some methods to increase the engineering efficiency. Examples are the standardization of the product with the design of the SIGMA combatant, the standardization of components and the implementation of the Vendor Delivery Data Schedule tool. This thesis focuses on the design of an efficient Workflow Management System.

Addressing of engineering information

A first requirement to achieve an efficient engineering process is providing the necessary information to an engineer. As mentioned in chapter two DSNS act as system integrator, and partly as system designer. The engineers, as well as Damen engineers and subcontractors are highly dependent on the availability of engineering information. Providing an engineer with information consists of two aspects. Firstly, engineering information has to be addressed to the right engineers. To push the information to the right project participants the relationship between engineering information has to be known. The complex relationships can be explained with the modeling of two transformation functions of engineering: system design and integration.

The integration of the systems is performed by DSNS with assistance from subcontractors. The system design however is also performed by suppliers and is input for the system integration. This difference is displayed in Figure 18, where the suppliers are grouped as separate group.

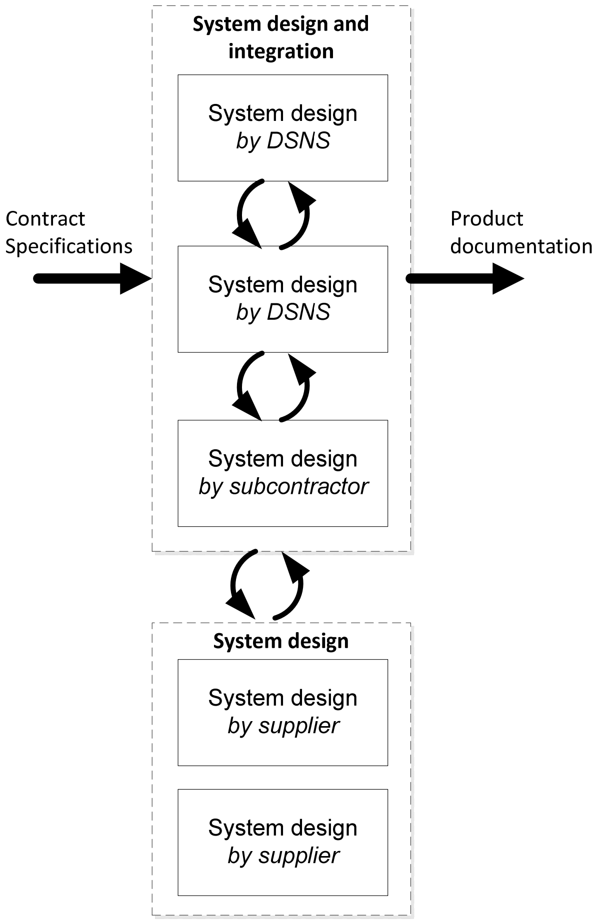


Figure 18 System design and integration is a concurrent process

For addressing information the relationship between information and the engineer has to be known. The relationship is defined by the complex product structure. The interrelation between activities is visualized with use of a matrix in Figure 19.

Example: The electrical engineer has to receive all engineering information concerning the electrical system. The system engineer which is making the technical requirements for tendering has to know all required interfaces of a special naval component. With about 250 systems and 10 to 60 thousand components the determination of all the relations will be difficult during a project.

Current implemented product structure does not contain all product relationships. Only the functional relationship between components is part of the product structure which means:

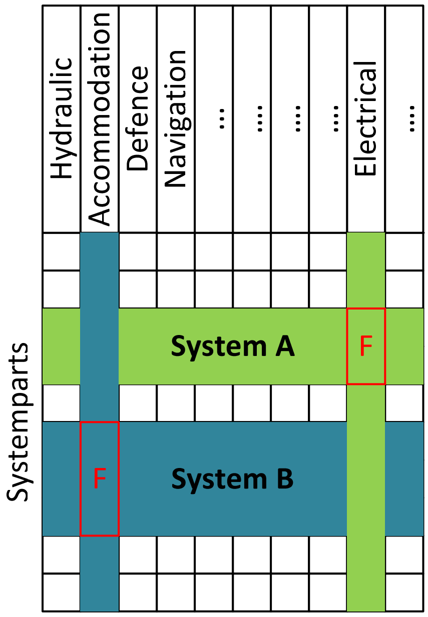
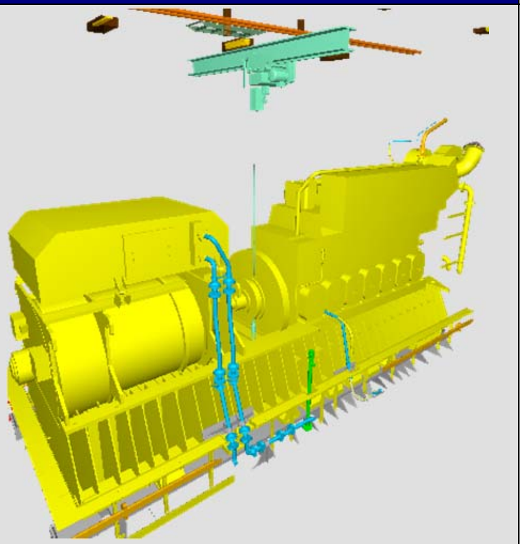


Figure 19 The system design and integration matrix

- The relationships between the components of e.g. the hydraulic system are known.
- The relationship between the users of hydraulic pressure and the hydraulic system are not registered by the product structure.

The product structure limits the determination of relationships between engineers and is not suitable for addressing information. The following example will explain the problem with the used product structure.

System (part) relations
Diesel Generator SET 2 of the Joint Support Ship belongs to system 13131. The Diesel Generator is connected to several systems. One of the systems is the 'fresh water cooling system', with system number 1592. The connected piping is displayed in blue color in the snapshot. The green Gantry Crane belongs to the Gantry Crane system with system number 1434. The Gantry Crane is related to the Diesel Generator.  The Product Breakdown Structure gives in the system structure no relation between the two system parts and the 'fresh water cooling system'. The only relationship can be found in the location of all system parts, which is space 01301. The space 01301 contains more than thousand system parts which belongs to about 40 systems.

Secondly, the efficiency of an engineer is dependent on the availability of accurate information. New available engineering information has to be pushed to the engineer. Engineering information is stepwise released by engineers according the iterative character of the engineering process. The lead time between release and receiving of engineering information has to be shortened to achieve a higher efficient process. Over time, the impact increase of new engineering information on a process. Moreover, making use of preliminary information or assumptions for a longer time than necessary, decrease the reliability of engineering information. The chance for rework increase with time.
The current Product Data Management system, which is responsible for information management, is not being able to push engineering information to engineers. Only tasks of the validation process of engineering documents are assigned to engineers.

Management of the ad-hoc information flows

The second requirement is managing of the engineering changes. The first condition is setup for the prevention of rework and is taken into account the planned engineering workflows. As stated in chapter two the engineering process is also influenced by unplanned, ad-hoc engineering workflows. New requirements of customer, new component specifications et cetera. These events result into ad-hoc engineering workflows. Also for these ad-hoc workflows the quick assignment to engineers is necessarily to decrease the amount of rework.

The ad-hoc information flows may result in extra costs for both the engineering and production process. The engineering process is spending extra hours which have influence on the production process also. According Damen employees the cost of implementation of revised manufacturing information during production will be about four times the costs of the initial spend engineering. Another applied rule is the rules of ten: the implementation of an engineering change will cost ten times more in every next phase (Watts, Engineering Documentation Control Handbook; Configuration Management and Product Lifecycle Management, 2012). The extra cost as caused by two aspects.

- Firstly, the effort which is needed to implement the engineering change. This is the same for engineering as production. Painting a wall all over again in another color will cause extra cost.
- Secondly, the cost of out-of-sequence work. The extra cost within this case can be covering of the painted floor, which wasn't painted before the first time painting of the wall. Out-of-sequence work will also give delay in other activities.

To limit the impact on the engineering and production process the engineering management has to be able to control the engineering change, caused by the ad-hoc information flow. The control has to analyze the impact of the change, called the change propagation, and consider a cost effective and efficient solution which has the lowest impact on the total cost and delivering time of the project. Above ad-hoc workflow management has to comply to the first condition for an efficient engineering process also: addressing to the right people and a short lead time.

Reliability of information

The third requirement is the assignment of maturity indication to engineering information. The engineering process cannot make all engineering information final before release of engineering information. Always a part of the engineering information will not be finished by the lack of engineering information. This is the consequence of the development process of naval vessels and the high dependability of engineering information from external participants. Therefore preliminary engineering information will be shared. The sharing of preliminary engineering information is also part of the concurrent engineering approach, used by the system design approach.

The system design and integration is performed by concurrent engineering, which means (Richardson & Dunne, 2010), (Hauptman & Hirji, 1996):

- Parallel design of systems
- Sharing of preliminary information
- Design start with preliminary information
- Two-way communication between functions
- Overlapping problem solving

Concurrent engineering, parallelization of activities, is used to shorten the lead time of the design process. The main property of concurrent engineering is the use of preliminary information instead of final information (Hauptman & Hirji, 1996) (Richardson & Dunne, 2010). The parallel time path of concurrent activities requires the use and release of preliminary information. The parallel activity is only possible with use of the preliminary information of the running parallel activity. The problem with preliminary information will be the reliability. In general employees don't want to release preliminary information, because it's not final, on the other hand people want to have this preliminary information to start their activity.

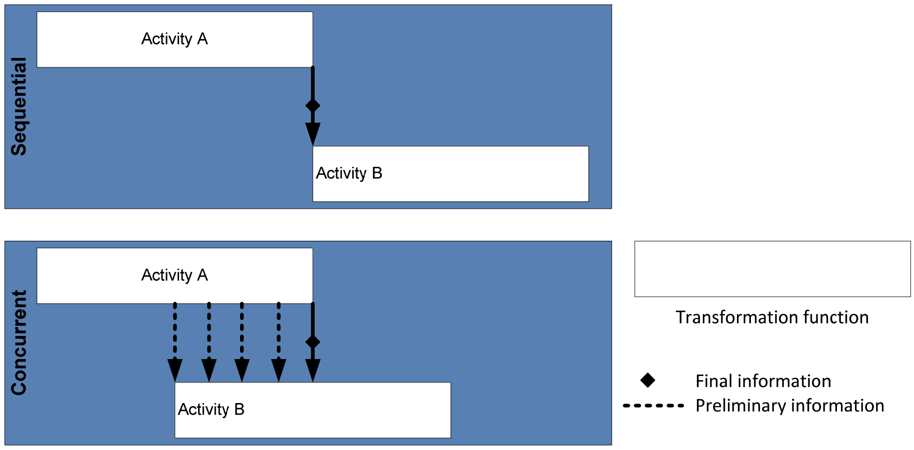


Figure 20 Information flow of a sequential and a concurrent process

To deal with this problem the information has to be estimated on its value. What's the reliability of the preliminary information, and which activity can be used? (e.g. can be used only to make an arrangement or can also be used for procurement, job preparation etc.) Therefore information has to be categorized with maturity levels. For example with the following categories: only description of requirements of the document, preliminary document or final document.

In the current process of DSNS only one information flow has an assigned maturity level. The component and system specifications supplied by the suppliers are decoded as preliminary or final. All other information flows doesn't have any maturity level except some annotations on documents.

To create awareness of involved project members the engineering information has to be decoded with a maturity level. This maturity level must not be assigned on engineering document level. As stated in chapter two engineering information doesn't have a similar maturity level in time. In practice an engineering document consists of several engineering information which hasn't all the same maturity level. An engineering document can be partly final. To overcome this difference in maturity level the maturity level of the engineering document has to be defined in more detail.

Manufacturing Engineering

The fourth requirement is the implementation of manufacturing engineering. Manufacturing Engineering is the integration or parallel execution of the two engineering function detail and job preparation. The transformation functions to release the manufacturing information consist of two functions: Detail Engineering and job Preparation. The current organization of these two processes is based on a sequential process. DSNS has the intention to change the sequential process into a concurrent process with the implementation of Manufacturing Engineering (see Appendix F).

Manufacturing Engineering (ME) will result in the integration of manufacturing information into the production information. In the current situation the production information is the output of Detail Engineering. Next the production information is transformed by job preparation into manufacturing information. Manufacturing information is defined as: 'Manufacturing instructions which can be used in the production environment.'

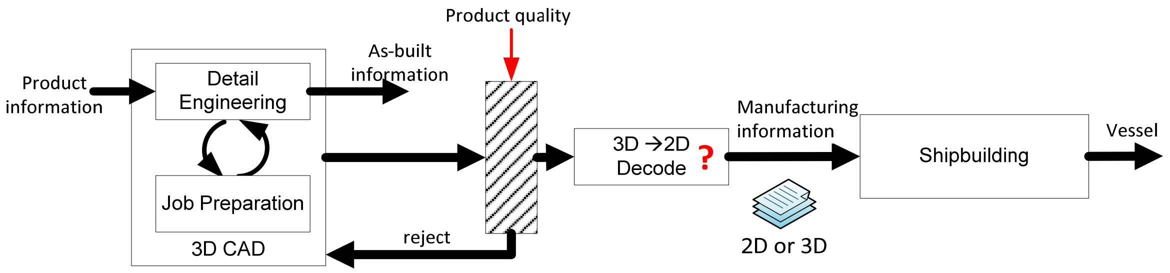


Figure 21 Manufacturing Engineering

With the implementation of manufacturing engineering the 3D CAD model can become the only communication tool between engineering and production. This will increase the effectiveness and efficiency of engineering. The lead time and effort for communication of ad-hoc information flows to production will decrease. The new role of the 3D CAD model requires the implementation of model control. The model control administrates the events applied to the 3D CAD model. This is necessary to communicate efficiently the new or changed production information to the shipyard. Part of the model control is the restriction of edits into the 3D CAD model dependent on the progress of the engineering process. The permission of editing of the 3D CAD model after release to the production will be part of the consideration of a cost effective and efficient implementation of an ad-hoc information flow. This consideration will be part of the management of the ad-hoc information flows. This consideration has to include also the progress and status of the production process.

Evaluation

Every repeated process has to be evaluated to improve the process. The engineering process of DSNS is a project and consists of a defined end state. The engineering project is not repeated under the same circumstances and with the same requirements. However the existing similarities between engineering projects require a project evaluation. The project evaluation has to be able to evaluate the aspects which will be similar over engineering projects. An example is the involvement of subcontractors, suppliers or components in several projects.

DSNS has implemented a Product Improvement Management System (PIMS), which is setup to collect issues which can give direction to process and product improvements. However PIMS assumes the knowledge of engineers about the source of a product or process issue. There is no system which is able to analyze process disruptions, usually due to ad-hoc information flows. Therefore project evaluation has to be able to analyze the ad-hoc information flows to trace the origin of them. Thereafter the source of the disruption has to be characterized as project specific or general applicable. The second group has to be further investigated.

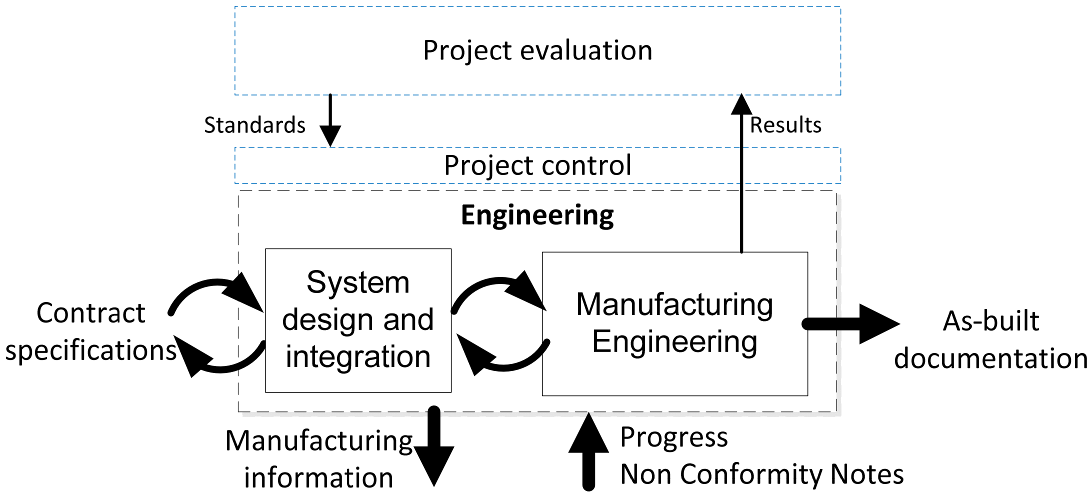


Figure 22 Project evaluation

3.3 Conclusion

Engineering have to comply with the requirements of low cost and delivering on time. To improve the current approach the following requirements can be implemented into the engineering process:

- Addressing engineering information to project participants in such a way that: firstly, the project participant receives the right engineering information and secondly, shortens the lead time between releasing and receiving of information.
- Control of the ad-hoc information flows to decrease the impact of them by analyzing the ad-hoc information flow and considers a cost effective and efficient solution which has the lowest impact on the total cost and delivering time of the project.
- The applied concurrent engineering approach requires the assignment of maturity levels to engineering information. The maturity level has to be assigned in more detail to parts of engineering documents.
- Implementation of manufacturing engineering which increase the efficiency of the engineering process and decrease the lead time between engineering and production.
- Disruptions of the engineering process have to be evaluated to improve the engineering project process of DSNS. The engineering disruptions, raised in ad-hoc information flows, have to be traced back to the source.

The first three requirements have to be part of a project control, the fourth requires the implementation of a new method for engineering and the last requirement is about the implementation of an evaluation function of the engineering process. The first three requirements will be part of a Workflow Management System. The engineering management is a functional part of the project control of the earlier defined ProPer model (Figure 23), by the following reasons:

- Firstly, the engineering management has to link the engineering activities, project participants and engineering information. The project participants are the third aspect flow of the ProPer model.
- Secondly, decisions during engineering are also based on the progress of the production process, especially with the management of ad-hoc information flows which can influence the production process also.

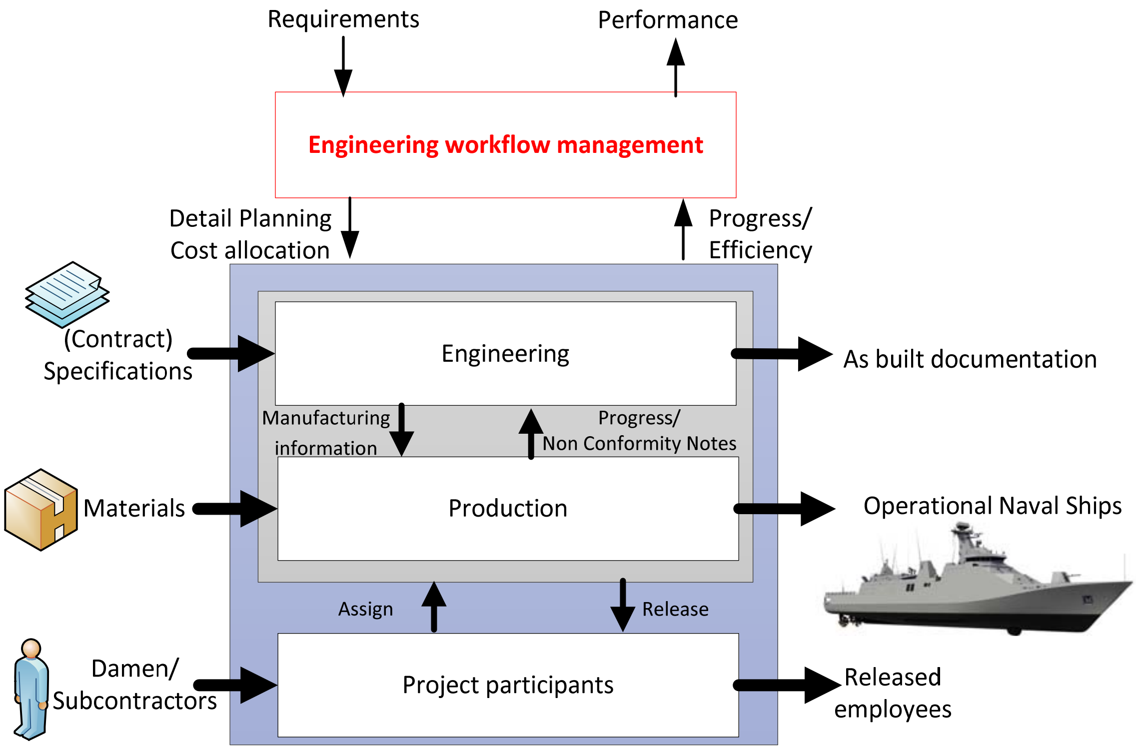


Figure 23 The project control of the proper model

4 Problem statement

4.1 Problem statement

The analysis of chapter three has resulted into three elements which need to be implemented into the engineering process of DSNS. Firstly, a Workflow Management System which is able to: address the engineering information to project participants, assignment of maturity levels and the management of ad-hoc information flows to result in an efficient and lowest cost solution. Secondly the implementation of manufacturing engineering which increases the effectiveness and efficiency of the release process of manufacturing information. Thirdly, the implementation of an evaluation process, which is able to suggest project process improvements.

The thesis will be focusing on the elements of the Workflow Management System. Therefore manufacturing engineering and the evaluation of project results will not be taken into account. To ensure a proper implementation of these elements in future, these elements will be part of the prerequisites of the implemented solutions.

The research question becomes:

"Develop a Workflow Management System that is able to manage the planned and ad-hoc information flows and contributes to:

- Lower cost
- Increased productivity of engineering
- Identical or shorter throughput time of engineering"

The engineering workflow

A Workflow is a set of sequential transformation functions. The transformation functions are the engineering tasks or activities. The engineering tasks are transforming engineering information from input to output. The definition of engineering information is wide. Engineering information are system drawings, arrangements, production drawings, component specifications, calculations et cetera. Also the 3D CAD model is engineering information. In addition of above mentioned data also minutes of meetings and e-mail is engineering information. They will usually describe engineering decisions and often give information how they came to that decision. In general engineering information is a wide term of all data which is important for a one-time-right and efficient engineering process.

A special part of the engineering information is the 3D CAD model. As seen in chapter three the implementation of Manufacturing Engineering gives the 3D CAD model a new role in the engineering process. The 3D CAD product model will become the communication tool between the engineering process and the shipyard. The model is an assembly engineering information as system parts and work instructions. The approach for management of this model is to deal with all system parts as separate engineering information. This also requires an adjustment to the 3D CAD product model. These adjustments are not part of this thesis.

A second part of the engineering workflows are the transformation functions. Within this thesis the focus will be on the transformation functions of engineering. The scope will be defined as the engineering activities from Effective Date of Contract (EDC) until the delivery of the manufacturing information. The delivery of engineering information for the settlement of warranty claims will also be part of the scope of the workflow management. The delivery of this information will be interpreted as revised manufacturing information as result of the warranty claim of the client.

4.2 Functional requirements of the Workflow Management System

The Workflow Management System (WMS) is the implementation of three elements, defined in chapter three. The three elements are the functional requirements of the WMS.

Addressing of engineering information

The planned and ad-hoc workflows need to be addressed to the right project participants, dependent on the role of the individual project participant. The engineer performs engineering tasks according to his role in the engineering project. The role of the engineer determines the required engineering information. Addressing of engineering information to engineers has to be extended with the following functions.

- Firstly, sending all relevant information to the right engineer. As earlier mentioned this means not only engineering drawings, but also engineering decisions, notes of other engineers et cetera.
- Secondly, notification of the engineering about the received information. Ad-hoc engineering information is not expected by the individual engineer and needs to be pushed to the engineer.

Assignment of maturity level

The engineering information has to be assigned with a maturity level. These maturity levels represents the reliability of information and gives guidance to the users of the engineering information according usability, probability of change et cetera. The elements which will be used for assignment of the maturity level will be a consideration between workload of administration and the required detail of maturity of engineering information. The element for administration of the maturity level may differ according the engineering information.

Ad-hoc information management

The ad-hoc engineering information has to be analyzed to determine the change propagation and influence on the engineering and production process. The workflow management will support this analysis. The ad-hoc workflows are defined during the project, contrary to the planned workflows. The workflow management has to be able to define in an efficient way the new originate workflows as consequence of the release of ad-hoc engineering information.

4.3 Prerequisites for the solution

In the previous paragraph the functional requirements of the proposed solution are listed. The following characteristics of the current used engineering process will constrain the Workflow Management System:

- The Workflow Management System has to be independent of other systems. The project participants are using different software, which most important are Cadmatic and Microstation. However subcontractors, suppliers and specialists also use other software. The input and output of the different software are many times incompatible. Most used software is developed for naval vessel design and can therefore not easily replaced by other software. The variation of subcontractors among projects makes the used software even more variable. Therefore the information management system has to be little dependent on the used software. The use of Teamcenter, Product Data Management, can be seen as stable software during engineering.

- Current validation process will be part of the Workflow Management System. The 2D engineering documents are controlled with use of the Product Data Management system. Every engineering document is subjected to a defined validation process. In general a validation process comprises of: Firstly, the check by the Team Leader and next the approval by the chief engineer. This release process is part of the Product Data Management system and works well. The release process is also part of the requirements for the ISO 9001 certification. The steps of the current release process will therefore be taken as input for the Workflow Management System.

- The Workflow Management System requires worldwide access by all project participants. The project is a transformation process of contract specifications into manufacturing information. This transformation process will be performed by many internal and external activities. The subcontracting of systems and the spreading of subcontractors around the world requires communication which should be able to overcome these (physical) distances between project participants. Furthermore, not all project participants have or get access to the Damen network.

- The Workflow Management System is able to handle the dynamic link between project activities and engineers. The project team is not a static team from Effective Date of Contract to handover of the naval vessel to the customer. Employees will be assigned and released during the project or will be replaced by other project participants. There is a dynamic link during the project between engineering information and responsible project participants.

- The Schelde System Work Breakdown Structure (SSWBS) will remain the organization structure for information. The SSWBS is highly integrated in product and activity definition. This system is also used for the product definition and is known by several customers. Furthermore the system structure is current implemented in all used software.

- The planned and ad-hoc engineering workflows need to be administrated for future analysis. During the engineering project questions about earlier design changes and design decisions need to be answered. This administration can also be used for improvement of the engineering process and product.

5 Workflow Management system

This chapter defines the Workflow Management System. Firstly, the definition of the engineering workflows using the product structure. Secondly, the relation of the engineering activities and documents to the defined engineering workflow. Thirdly, the engineering document validation which is performed with the assignment of a maturity level. Fourthly, the engineering change procedure will be defined. Finally, the communication and administration of the workflows is defined. The implementation of the Workflow Management System is worked out in chapter six.

5.1 Workflow definition

In the first place the engineering workflow has to be defined. The engineering workflow is a set of sequential engineering activities, and can be characterized as follows (Bijwaard, Spee, & de Boer, 2000):

- The engineering activity adds value by transformation of input data into output data.
- The engineering activities are highly related to each other by the complex relations: part-of, version-of and alternative-for.
- To limit the project duration many engineering activities will be performed in parallel, the so called concurrent engineering approach.
- Frequent process changes of the engineering processes. The process is started with a set of planned workflows. Engineering changes results in process changes and ad-hoc engineering workflows.
- The engineering process is commonly characterized by iterations. Therefore the link between engineering information and engineering process needs to be maintained.
- Engineering information will exist in multiple maturity levels. Where one component is already completely detail engineered, another component is still only specified. This difference in maturity level will also be caused by engineering changes.

Product centered workflow management

The classical workflow management is well suited for handling of planned workflows. The activities and exchange of engineering information is defined before the start of the project. The classical workflow management is insufficient in the management of the ad-hoc information, resulting in ad-hoc workflows. It is not able to properly address the ad-hoc information by definition of the ad-hoc workflow. A solution could be the use of the product-structure as basis for the workflow management (Roubaih & Caskey, 2003). Joeris defines the product-centered aspect as one of the requirements for workflow management within a product design environment (Joeris, 1997). Engineering document changes will propagate through product relations to other documents and accessory engineering activities. These product relations have to be known for proper control of the ad-hoc workflows and are defined in the product structure. The difference of the classical workflow and the product centered workflow is visualized in Figure 24.

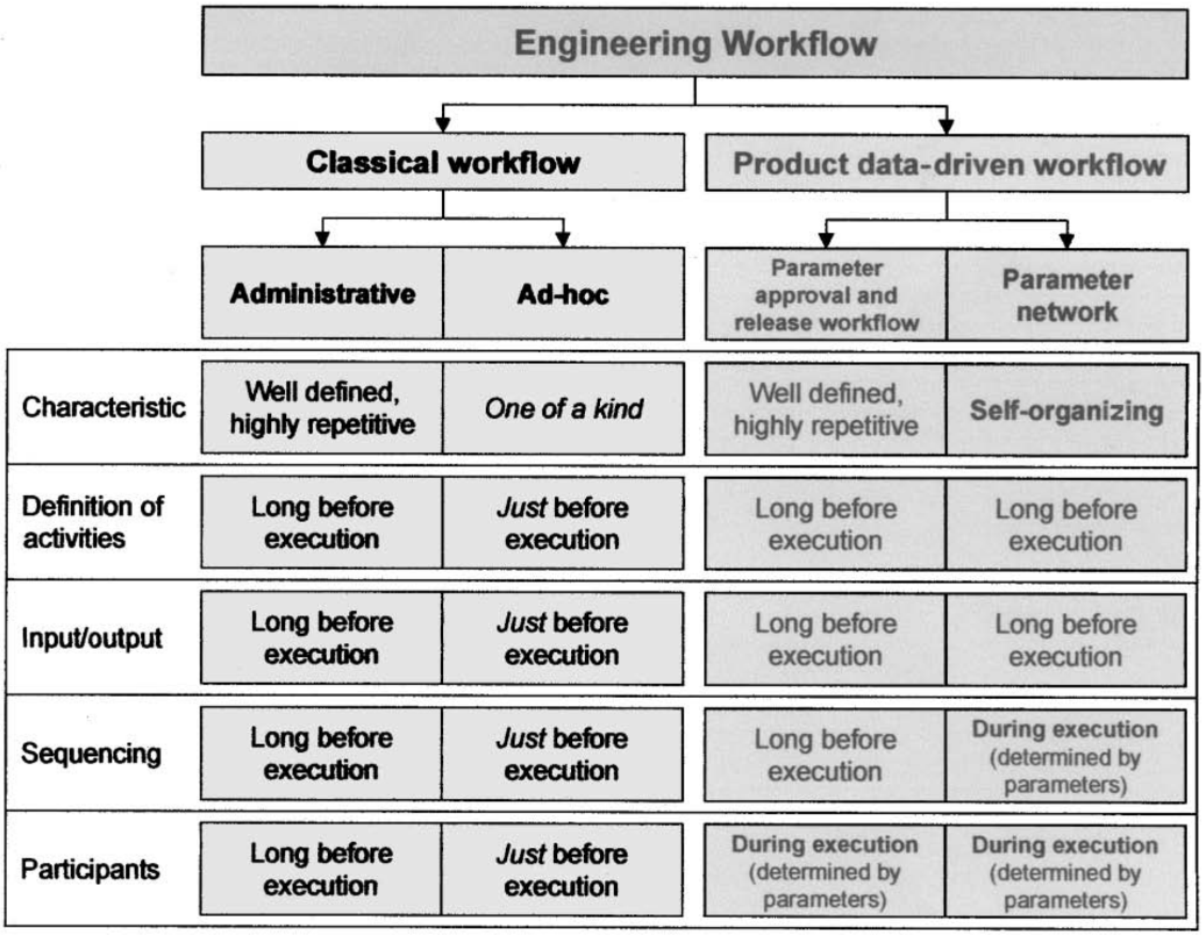
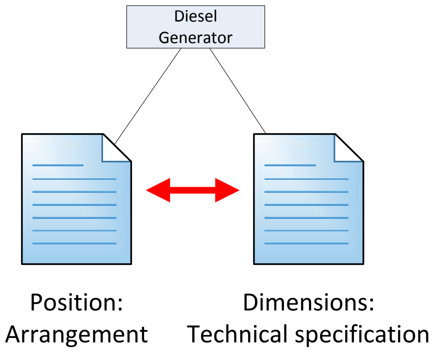


Figure 24 Classical workflow versus product-centered workflow definition (Roubaih & Caskey, 2003, p. 278)

> *An example is the technical specification document, specifying the component, and a vessel arrangement which defines the position of the component on the vessel. The position of the component is based on the dimension of the component described in the technical specifications.*
> *For example the foundation of a diesel generator is drawn on a foundation drawing. The foundation is based on the position and the footprint of the diesel generator. This*

footprint and position can be found in the technical specification of the diesel generator and the arrangement of the engine room.



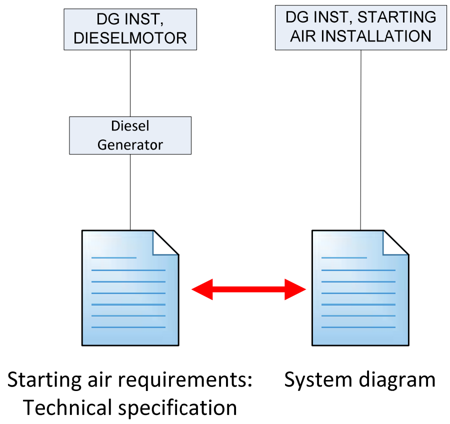


Figure 25 Documents containing different relation values of the same system part

Figure 26 relation values of documents are dependent through system (part) dependence

Schelde System Work Breakdown Structure

A common method of product dependency definition is the Design Structure Matrix (DSM). In general, the component based DSM is applied, which shows the dependence between components in a n x n matrix. It shows the dependency between components or systems. Using the component based DSM has two disadvantages. Firstly, the dependence between components is currently not administrated and therefore the setup of this matrix will require much extra work. Secondly, the component based DSM does not clearly visualize the presence of multiple dependencies between components. These multiple dependencies are very important within the estimation of engineering change propagation (Habhouba, Cherkaoui, & Desrochers, 2011).

Roubaih and Caskey developed the parameter based engineering (change) management, part of the SIMNET project[1] (Rouibah & Caskey, 2003) (Yang, Goltz, & Han, 2004). This method is using a parameter-based DSM. A selection of parameters defines the direct and indirect dependencies between components. The dependences are displayed with use of a parameter network. Also the parameter-based DSM requires extra work with the definition and registration of all parameters into one database.

[1] Workflow Management for Simultaneous Engineering Networks. Funded by the Commission of the European Communities under the ESPRIT programme (EP 26780)

For minimization of the extra work and cost the Workflow Management System has to use the existing product structure with the available dependencies. The product structure is defined by the Schelde System Work Breakdown Structure (SSWBS). In this structure every system part (component) is member of one system of the SSWBS. The relation is based on the function of the system part. The system parts of the hydraulic system are all system parts which are fulfilling the function 'providing hydraulic pressure for other components'. The relation of the system part is expressed in the system part coding, which includes a system number. The DSM is becoming a relation-based design structure matrix.

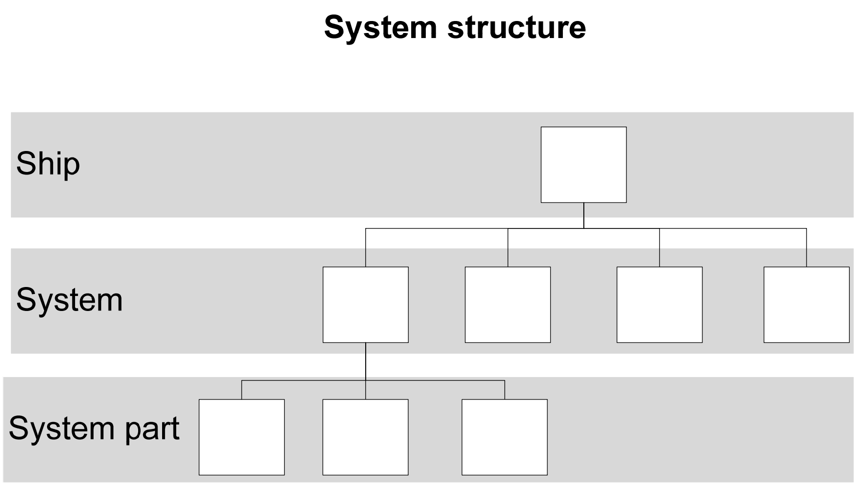


Figure 27 System structure of DSNS

Product Relation Matrix

The Product Relation Matrix (PRM) defines the relation between a component and one or more systems of the SSWBS. A dependency between components is defined by the relation of both components to an identical system: Component ←→System ←→ Component.

> *The 13131XA0001AA V12 Diesel Generator set and the 1612XA0001AA Starting Air Compressor are both related to the 1612 Starting Air System and are therefore mutual dependent.*

The dependencies are defined with use of the existing product structure and minimize the extra work to define all dependencies between components. The dependency of a component to a system will be named a relation. The Product Relation Matrix is the collection of all relations. The objects of the matrix are the components of the product. The aspects of the matrix are the systems of the product, retrieved from the SSWBS.

The relationship between a component and a system is defined with a relation. The relation can be a functional relation: "The component is a functional part of the system." The functional relations are already registered in current Product Data Management system. The second group is the interface relations: "The component is for operation dependent on the system and has therefore an interface to the system."

> *The Diesel Generator is functional member of the Diesel Generator system and has an interface relation to the Starting Air System. The Compressor has a Functional relation to the Starting Air System. Both system parts have an interface relation with the hoisting system. The hoisting system is required for the exchange of components on board and will be performed with use of a gantry crane in the Diesel Generator Room. The Crane has a functional relation with the hoisting system.*

System part	Description	13131 DG system	1612 Starting Air	1300 Eletrical system	1434 Crabbing Cranes
JS13131 - XA0001AA	V12 DIESEL GENERATOR SET 1 SB FWD	F	I		I
JS13131 - XE0009AA	24VDC SUPPLY CABINET DG SET 1	F		I	I
JS13131 - XE0016AA	ENGINE CONTROL CABINET V12 DG SET 1	F		I	I
JS13131 - XE0020AA	JUNCTIONBOX ON ENG V12	F		I	I
JS13131 - XE0030AA	RESISTOR JUNCTION BOX	F		I	
JS1612 - XA0001AA	STARTING AIR COMPRESSOR D G RM 1		F		
JS1434 - XA0002AA	DG1 GANTRY CRANE				F

Figure 28 The Product Relation Matrix

Engineering workflow definition

With the definition of the PRM the definition of an engineering workflow becomes: "The sequential engineering transformation functions applied to one relation." The engineering transformation functions are the engineering activities, or otherwise called the engineering tasks. The engineering workflow defines the dependency between engineering information and the accessory activities.

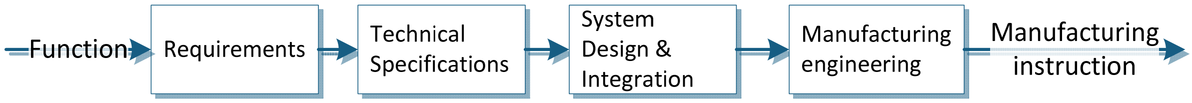


Figure 29 Engineering workflow

The engineering functions of a workflow are performed parallel and sequential. The first situation occurs with the parallel system design, part of the concurrent engineering approach. The sequential engineering functions will be visualized as layers on the Product Model Matrix. The engineering workflow of a relation are the engineering activities, represented by layers, from bottom up to the final released manufacturing information (see Figure 30). Every layer characterizes a special engineering function applied to the relation definition. The engineering functions are defined according the engineering activity groups, based on the Work Breakdown Structure (see Appendix E). The engineering workflow of the different relations will differ.

One layer is containing all system diagrams. These system diagrams define the mechanical systems of the naval vessel. These system diagrams are describing an aspect system of the Product Model Matrix. The aspect systems are positioned vertical parallel to each other on the layer. The Navigation Lighting Systems however is not defined with use of a system diagram. That system will not have the relation activity of mechanical definition of the system.

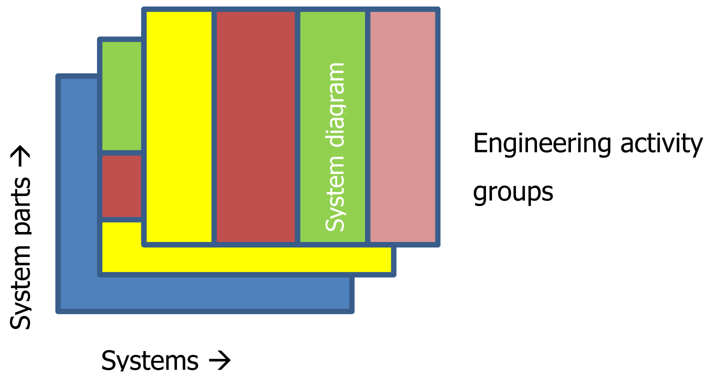


Figure 30 Relation activities displayed with layer structure

The content of an engineering document

The Product Model Matrix is a collection of all relations. An engineering document defines one step of the engineering workflow. The document is not restricted to one relation but defines multiple relations. The collection is a sub- or aspect system of the Product Model Matrix. The definition of an engineering document becomes: "An engineering document captures the results (relation value) of one engineering transformation function applied to a collection of relations." The relation value is: "A set of product parameters which defines the relation in detail".

Partial collections can be composited by sub- and aspect systems. An aspect system is a partial collection of the relationships in the product, whereby all the original objects remain unchanged. (Veeke, Ottjes, & Lodewijks, 2008) The aspect system contains one or more columns of the product information matrix. The hydraulic aspect system is defined by all relations in column one. A subsystem is a partial collection of objects for which all the relationships remain unchanged. (Veeke, Ottjes, & Lodewijks, 2008) A subsystem contains one or more rows of the Product Relation Matrix.

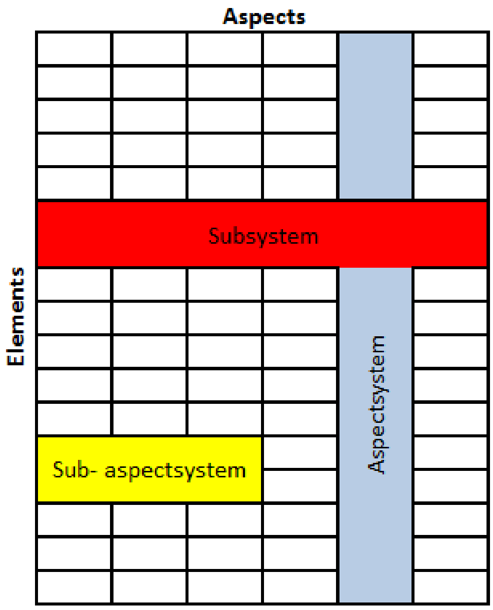


Figure 31 Aspect- and subsystems

The system diagram of the Starting Air System specifies one aspect system. The diagram defines the unity between the functional and interface relations. The diagram defines the pressure of the starting air, the physical interfaces between the components and the location of the system parts.

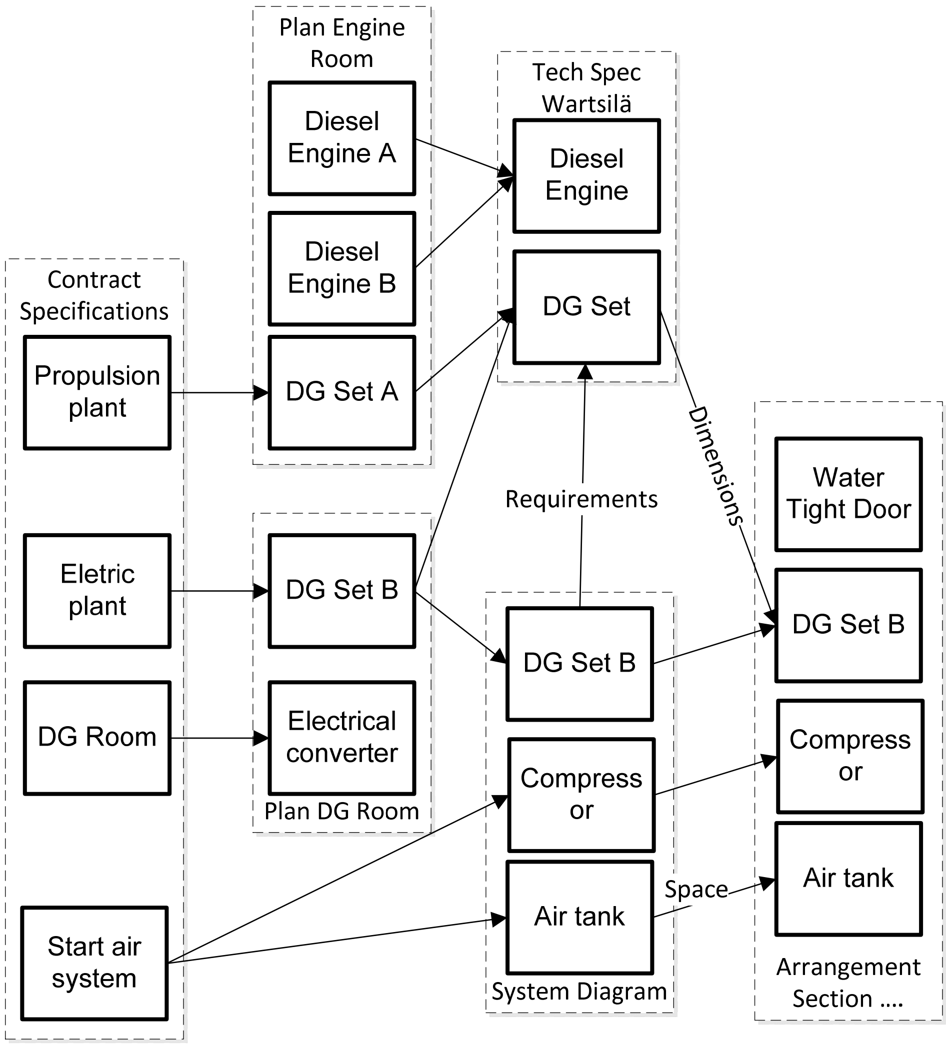


Figure 32 Examples of aspect- and subsystems in an engineering workflow

The engineering document is called a system oriented document if the collection of relations can be typified as an aspect system. A spatial-oriented document (document describing a defined spatial part of the naval vessel) contains a collection defined with a subsystem.

5.2 Communication and administration

In the previous paragraphs a definition is given of the used product structure. The product structure will be used for communication, notification and administration of engineering information.

Addressing to the engineer

An engineering activity structure is identical to the engineering document structure. The activities and documents are linked to each other by the document and activity ID. For each project a document list is made containing all planned documents. The document list will be input for the activity planning. A screenshot of the activity planning is shown in Figure 33. The activity ID number is similar to the document ID number. The engineering activities are defined with use of the corresponding engineering document. Therefore the setup of the information management will be defined with use of the engineering documents.

Activity ID	-Document ID-	Activity Nme	TEAM	DISTRIBUTION CLSS
E1405001	E14050.01	TOP 12K DESIGN PLN	T12	FI
E1623130	E16231.30	PLN OF STIRS	T12	
E1624001	E16240.01	PLN OF DOORS ND HTCHES: INTERIOR	T12	F
E1640001	E16400.01	FURNITURE LIST	T12	
E1070002	E10700.02	DMGE CONTROL PLN	T12	F
E1422201	E14222.01	PLN OF NVIGTION LIGHTING	T12	F
E1625001	E16250.01	PLN OF PORT LIGHTS ND WINDOWS	T12	F
E1631101	E16311.01	LIST OF COLORS	T12	
E1635501	E16355.01	PLN OF LININGS ND CEILINGS	T12	FI
E1084001	E10840.01	PLN OF TRNSPORT ROUTES	T12	
E1050002	E10500.02	SPCE/COMPRTMENT IDENTIFICTION PLN	T12	FI

Figure 33 Relationship between Activity ID and Document ID

Every engineering activity is assigned to a group of engineers, all having their individual role to the engineering activity. The flow of information will be:

Engineering information → Relation → Engineering Activity → Engineer

In this way the engineer will receive the right information and will be prevented from overload of engineering information. Individual engineers have to be able to enlarge the receiving of information by assignment to extra engineering activities, collections or individual relations.

The engineers will be supported with an information portal which provides access to the received engineering information. New information will be added to the portal during the project, maturity levels changes and even the Product Relation Matrix can extend during the process with the adding of new systems or system parts. The engineering has to be notified for new or changed information and has to be supplied with an engineering information overview.

Information

The engineering information is not limited to the engineering drawings and other official design documents. There is much more information available which will describe, define or have another contribution to the engineering process. Notes of engineers, progress reports, minutes of meeting, et cetera. For example the minutes of meeting which will give guidance to the engineering process and includes engineering decisions, explanation of client et cetera. All these information has to be handover to the engineer for an efficient and effectiveness process. Addressing of this information can be performed with use of the PRM. The information is assigned to a collection of relations and in this way the project participants are addressed with all required information.

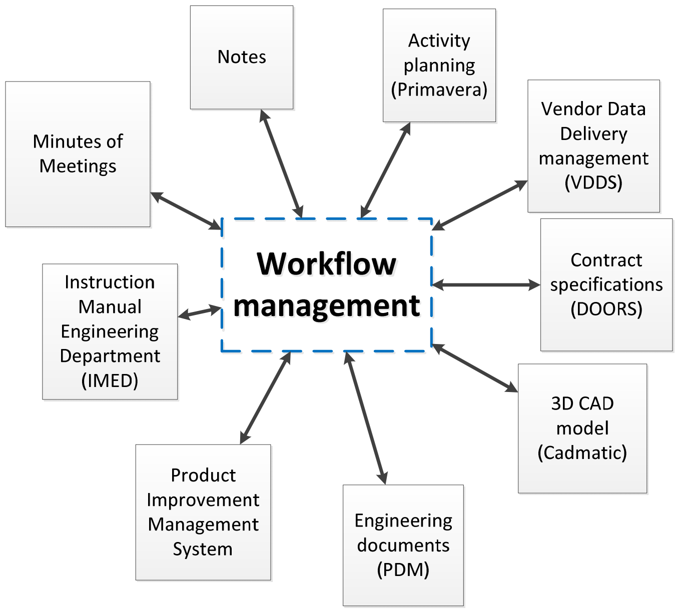


Figure 34 Information linked to the Workflow Management System

Engineering change documentation

A very important part of the workflow management is the administration of the engineering process. During the engineering process decisions are made and engineering changes are applied to the design. The engineering process can become a source of information for future processes. An engineering change can become a disturbance for the process of engineering and production. Disturbance analysis will be based on the engineering changes and has to be able to track back to the origin of the engineering changes.

The engineering change document contains four parts. Firstly, the origin of the engineering change has to be administrated. Which relation of the PRM is the origin of the engineering change? The causal relations between engineering changes have to be administrated, for trackback to the origin of the engineering change. The engineering change of that relation has to be described and the necessity has to be argued. This argument has to be administrated during the engineering process and will be part of the engineering change procedure. Secondly, the change propagation has to be administrated. The affected relations are a consequence of the engineering change. Thirdly, the required revision of engineering documents has to be administrated. This administration will be useful for trackback the engineering revision to the origin of the engineering change. Finally, known consequences for other processes, as logistics, production or subcontractors, can be added to the engineering change administration.

5.3 Engineering document validation

Maturity level evolution

The second functional requirement is the assignment of maturity levels to engineering information. Engineering changes are documented with the use of document revisions. However the document revision registration is missing the required maturity level detail for a concurrent engineering approach. The sharing of preliminary documents requires an indication of the maturity level of the content of the document. The maturity level of preliminary documents cannot be captured within a general validation status of the complete document.

Therefore the maturity level will be assigned to every relation of an engineering document. This will result in a maturity level for every iteration step of a relation value. When a relation workflow consists of five engineering activities, the relation value will be assigned with five maturity levels.

The system engineer will setup the requirements for the Diesel Generator and accessory system parts to order the DG set. The system engineer is dependent on the information of the electrical engineer and wants to know the maturity level of the electrical design. , The system engineer is interested in a subsystem.

System part	Description	13131 DG system	1612 Starting Air	1300 Eletrical system	1434 Crabbing Cranes
JS13131 - XA0001AA	V12 DIESEL GENERATOR SET 1 SB FWD	F	I		I
JS13131 - XE0009AA	24VDC SUPPLY CABINET DG SET 1	F		I	I
JS13131 - XE0016AA	ENGINE CONTROL CABINET V12 DG SET 1	F		I	I
JS13131 - XE0020AA	JUNCTIONBOX ON ENG V12	F		I	I
JS13131 - XE0030AA	RESISTOR JUNCTION BOX	F		I	
JS1612 - XA0001AA	STARTING AIR COMPRESSOR D G RM 1		F		
JS1434 - XA0002AA	DG1 GANTRY CRANE				F

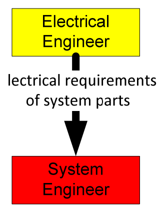


Figure 35 Maturity level of information

Relation activity A	Unworked
	Preliminary
	Final
	In check
	Approved
Relation activity B	Unworked
	Preliminary
	Final
	In check
	Approved
Relation acitivity C	Unworked
	Preliminary
	Final
	In check
	Approved

Figure 36 Maturity level assigned to the relation values

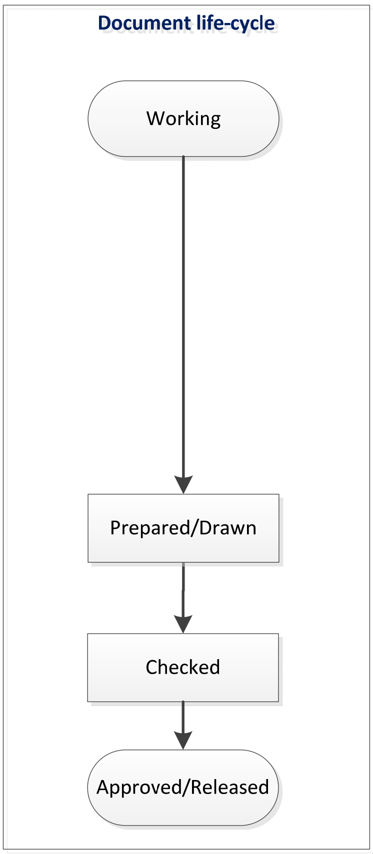


Figure 37 Validation process of engineering documents

The maturity level defines the reliability of the relation value captured in the linked engineering document. The engineering document contains a collection of relation values. The maturity level of the relation value captured by one engineering document may differ. Therefore the maturity level has to be administrated for every relation value in particular. The maturity levels are:

- Unworked: The relation value is unknown.
- Preliminary: The relation value is captured with a preliminary value.
- Final: The relation value is final but not validated.
- In check: The relation value is in process for validation and will be checked by the Team Leader.
- Approved: The relation value is approved by the Chief engineer.

Product definition level

Detailing the maturity level to the individual relation values captures in the engineering document will give enough detail to the engineer. However the available detail in the engineering document is dependent on the product definition level of the document. The product definition level of the engineering documents is dependent on the scope of the document, in relation to the system engineering approach (
Figure 38). The product definition level is: "The available detail captured by the engineering document typified according the system breakdown structure".

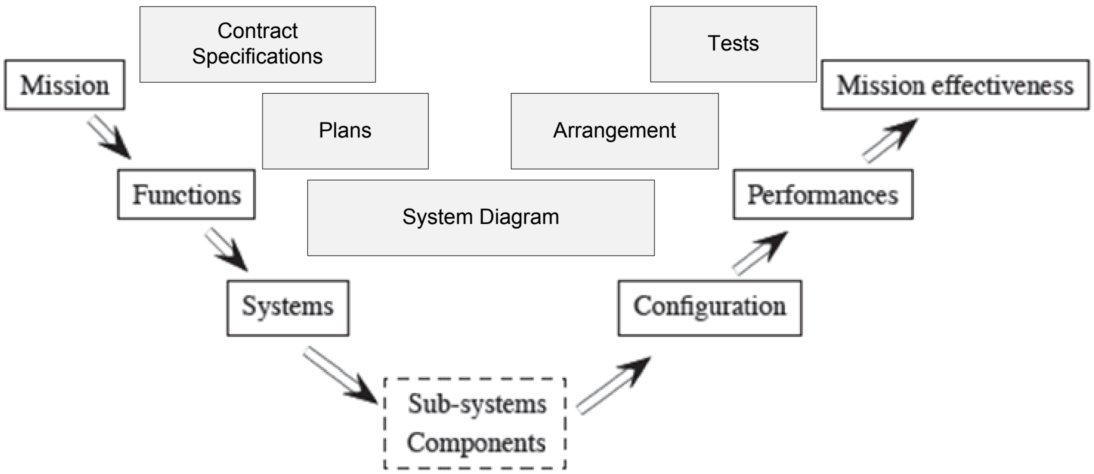


Figure 38 Level of product definition edited (Coenen, 2008, p. 4)

The Starting Air System diagram defines the mechanical design of all functional and interface relations of the Starting Air System. The smallest defined product details are the components of the naval vessel.

The lowest detail of the fire safety plans is one system of the naval vessel.

The fire safety plan of Figure 39 mentions all required components to achieve the fire safety requirements of class. This document is made after EDC and gives the requirements for the vessel design. It will include the positioning of fire extinguishers but also special requirements for some doors which have a special functioning during a fire accident. The components on the fire safety plan don't have a system part identification number yet. A special watertight door will get the system part number during the design of all doors on board. The fire safety plan will have an accessory list with all required components:

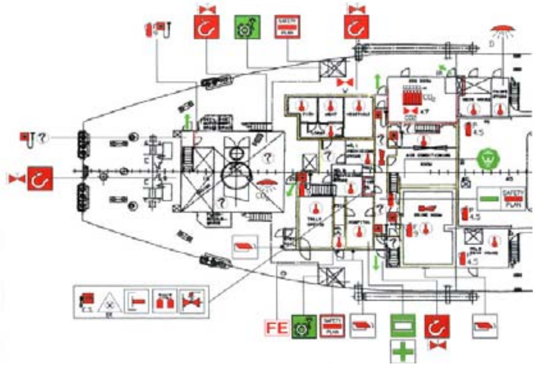


Figure 39 Fire Safety Plan (Seacurity)

- *5 fire extinguishers*
- *10 smoke detectors*
- *.....*

The maturity level will be based on the product definition level of the engineering document. Above fire safety plan defines the necessary system parts and the positioning of these system parts. However the components have no system part number. The system part number is a required aspect to define an individual relation. Therefore available detail for the management of the maturity level of the fire safety plan can only be performed on system level. The Workflow Management System has to be able to assign the maturity level to different levels of detail without missing the link to the individual relation.

5.4 Engineering change procedure

A sufficient engineering (change) management system links data, project participants and processes or activities together. These three elements can also be found in the three functions which can be derived from Watts definition of configuration management: "A simple, make-sense, fast, accurate, efficient, measured, and well-understood process approach to planning, identifying, controlling, and tracking a product's configuration from its inception throughout its life with minimum cost. " (Watts, 2012, p. 8).

The four functions in the definition of Watts are: planning, identifying, controlling and tracking. The functionality description of Engineering Change Management by Rouibah turns on the same functions (Rouibah, 2002):

- **Tracking** the impact of the change on elements of the product configuration

- **Identify** the involved participants
- **Control and plan** a new approval and release process (or workflow) to affect the engineering change.

Above three functions are currently not properly organized and standardized. The Product Relation Matrix will have a central role during the engineering change procedure. The PRM gives direction to the engineering change procedure and supports the engineers with the functions of tracking and identifying.

The PRM will be extended with an accessory relation network. The relation network is a visualization of the PRM. The network is developed to support the engineer who prefers the visualization within a network above the use a matrix (Keller, Eckert, & Clarkson, 2005). The network displays the mutual dependences between the relations.

The analysis of the engineering change comprises four steps. Firstly, the engineering change will be linked to a relation. The relation will become 'In change' and becomes the origin of the engineering change process. Secondly, determination of engineering propagation to the other relations of the system part (horizontal change propagation). Thirdly, determination of vertical engineering change propagation to other aspect systems of the affected relations. Finally, if aspect systems are affected the affected relations of these aspect systems has to be listed. These relations become the starting of a new iteration step following the four steps. The procedure will stop if no more new propagations have been found. Finally, the known change propagation can be discussed and a solution can be defined.

This analysis can be visualized by the relation network. In Figure 40 a relation network is made, based on the Product Model Matrix of Figure 28. The relations are one line and the nodes are system parts (elements) and systems (aspects) of the product. The relationships between system parts can be visualized within the network. For example component B is dependent with component C through the Electrical system (1300), DG system (13131) and the Crabbing Cranes (1434). Component B and C have multiple dependencies.

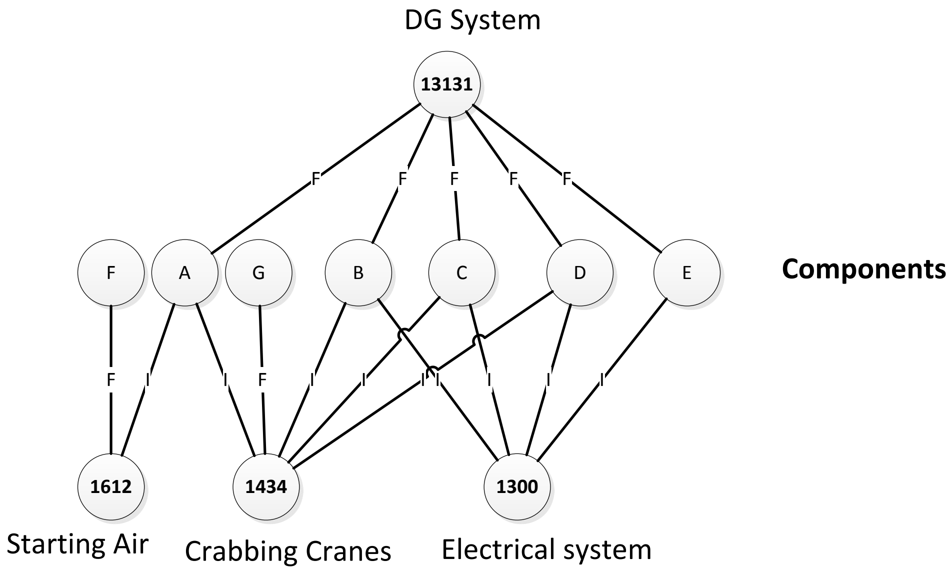


Figure 40 Relation network with the relations on line and the components and systems on node.

Another method to visualize the relationship between two components within a product is Component based Design Structure Matrix (DSM). A DSM however doesn't display the aspect for which the relationship is found. A Component based DSM gives a relation between all components, based on the electrical system. To display the multiple dependencies between components the relation-based DSM can be used (Browning, 2001).

> *The role of the relation network will be described with an example of an engineering change. An engineering document changes. The engineering document is linked to a relation. The first step is to define the impact of the revised engineering information. The new engineering information may result in changes to other components. The change can be direct or indirect* (Keller, Eckert, & Clarkson, Multiple Vies to Support Engineering Change Management for Complex Products, 2005)*. The direct change is to a direct connected component, whereby an indirect change is about a component which is not direct connected. The direct changes are in general easily detected, which is not the case with indirect changes. With use of the relation network the direct and indirect changes can be listed with the following method.*

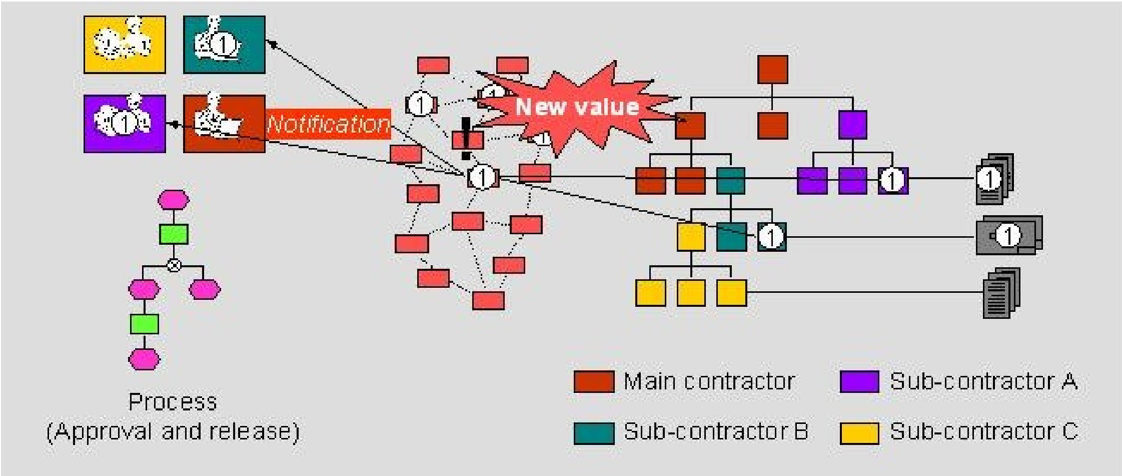


Figure 41 Tracking the direct change propagation (Schmitt R. , 2005)

The relation linked to the revised engineering document will be marked as new value. First the possible direct changes are listed with use of the relation network. All direct connected relations values will be marked with the digit one. The linked employees are notified and have to decide if the marked relations will change as consequence of the new relation value. The marked relations which will change remain marked and will be the input for the second step (Figure 42)

The marked relations will be considered as new values and the above described step will be repeated. The direct connected values will be marked with the digit two. The linked employees will be notified and for every relation will be decided if the relation will change. The procedure will stop if no more new relations will be marked.

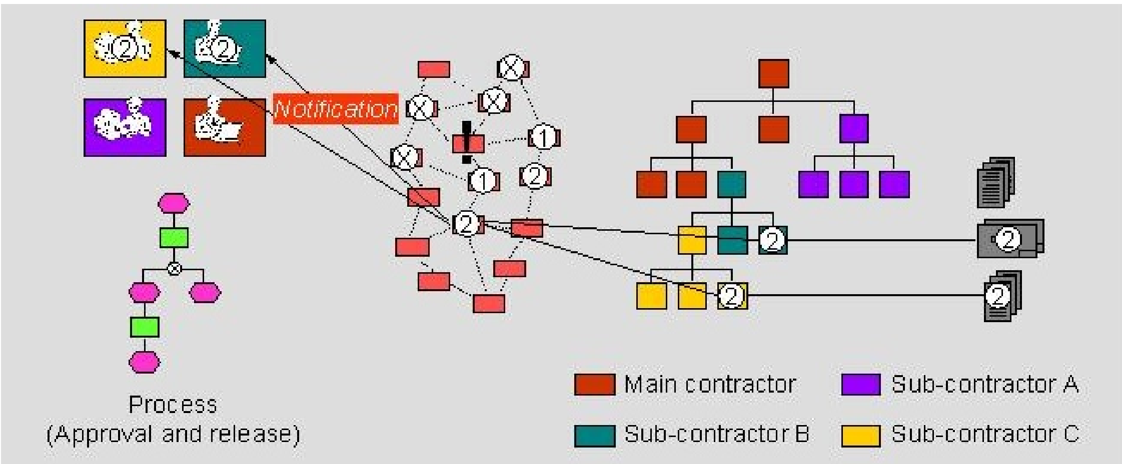


Figure 42 Tracking the indirect change propagation (Schmitt D. R., 2005)

All marked relations will be listed and marked with the maturity level 'in change'. With the listed relations the linked project participants are known and a meeting can be planned to discuss the engineering change. After implementation the relations will get the maturity level: 'revised'.

6 Implementation proposal

The defined Workflow Management System will be implemented into the current engineering process, whereby several adjustments to the current process are necessary. The structure of the implementation proposal is in accordance with the timeline of an engineering project.

Firstly, the project startup where the systems are defined and registered in the Product Relation Matrix. Secondly, the registration of systems parts in the Workflow Management System. Thirdly, the definition of the roles and authorizations of the project participants. Fourthly, the validation process of the relation values. Fifthly, the definition of the engineering change procedure and the role of the WMS in them. Sixthly, the data structure of the Workflow Management System. Finally, the benefits of the WMS.

The definition of the WMS is if necessary complemented with a Process Description Language (PDL). The PDL gives the definition of parts of the WMS and describes procedures and functions.

6.1 Project startup

The role of the WMS starts with the setup of the engineering project. During the setup of the engineering project the elements of the engineering workflows will be defined. The beginning of the project is defined by the Effective Date of Contract. However, several activities and documents are made before EDC to guarantee a good startup of the project.

The contract specifications become the input for the project startup. The Project Manager Engineering (PME) is making the Engineering Activity List (EAL). The EAL defines the required engineering activities of the project. The EAL is related to the applied System Work Breakdown Structure (SWBS), which is also defined by startup.

6.1.1 Setup of the Product Model matrix

The functioning of the Workflow Management System is based on the Product Relation Matrix (PRM). The engineering process starts with an empty PRM. The PRM consists of the systems, systems parts and mutual relations between them.

The first step is the definition of the systems with defining the applied System Work Breakdown Structure (SWBS). This SWBS is composited according the Schelde System Breakdown Structure (SSWBS) and contains a partial collection of the available systems in the SSWBS. The defined systems of the SWBS are registered in Teamcenter and transferred as aspect systems to PRM.

0000 - GUIDANCE AND ADMINISTRATION
    000X - GUIDANCE AND ADMINISTRATION
    060X - SUBSYSTEM CHARACTERISTICS
    0610 - HULL CHARACTERISTICS
        incl. General description of the construction
    0620 - PROPULSION SYSTEM CHARACTERISTICS
        incl. General description of the propulsion
    0630 - ELECTRICAL PLANT CHARACTERISTICS
        incl. General description of the electric system
    0640 - COMBAT AND SURVEILLANCE SYSTEM CHARACTERISTICS
        incl. General description of the combat system, incl. weapon systems
    0650 - AUXILIARY SYSTEMS CHARACTERISTICS
        incl. General description of de auxiliary systems
    0660 - OUTFITTING CHARACTERISTICS
        incl. General description of de accommodation, incl. hotel systems
    0670 - ARMAMENT CHARACTERISTICS
        incl. General description of de weapon systems
1000 - HULL STRUCTURE
2000 - PROPULSION PLANT
3000 - ELECTRIC PLANT
4000 - COMMAND AND SURVEILLANCE
5000 - AUXILIARY SYSTEMS
6000 - OUTFIT AND FURNISHING
7000 - ARMAMENT
8000 - INTEGRATION ENGINEERING GENERAL
9000 - SHIP ASSEMBLY AND SUPPORT SERVICES
F00 - LOADS
P000 - COSTS SURCHARGES
S000 - SALES ITEMS
Z000 - TEMPORARY LOCATION FOR LOGISTIC COST

Table 1 The chapters of the Schelde Ship Work Breakdown Structure

System Work Breakdown Structure

The Product Relation Matrix contains the aspect systems of the product. The aspect systems are defined according the SWBS, and are characterized by a tree structure. At higher aggregation level the different aspect systems are defined, at a lower aggregation level the aspect-aspect systems are defined.

In Table 2 the 3100 Electrical Power Generation system is worked out. The 3100 system is again an aspect system of the 3000 Electric Plant. Looking ahead, a document possibly defines an aspect-aspect system as 3111 Main Generator Diesel Engines or defines all systems of the 3100 Electrical Power Generation.

Level 1

SSWBS	*Description*
3xxx	Electric Plant
4xxx	Command and Surveillance
5xxx	Auxiliary system

Level 2

SSWBS	*Description*
31xx	ELECTRIC POWER GENERATION
32xx	POWER DISTRIBUTION SYSTEMS
33xx	LIGHTING SYSTEM
34xx	POWER GENERATION SUPPORT SYSTEMS
39xx	POWER MANAGEMENT SYSTEM

Level 3

SSWBS	*Description*
3102	Main Electrical System Automation
3110	SHIP SERVICE POWER GENERATION
3111	Main Generator Diesel Engines
3112	Main Generators
3113	Shaft Alternator (PTO)
3120	EMERGENCY POWER GENERATION
3121	Emergency Generator Diesel Engine
3122	Emergency Generator
3130	BATTERIES AND SERVICE FACILITIES
3131	Battery systems
3132	Uninterrupted Power Supply (UPS) systems
3140	POWER CONVERSION EQUIPMENT
3141	Transformers
3142	Frequency Convertors
3143	24 V DC Supplies
3144	400 Hz, 115 V supplies

Table 2 System and subsystem definition

The different aggregation levels of the SWBS will be coded with three systems levels. These three levels are incorporated into the PRM. The relations between systems parts and systems are registered at the third system level. However, the other two levels, which are together the tree structure of the SSWBS, will also being implemented in the PRM. The implementation of the other two levels has three reasons:

- Firstly, the possibility for registration and linking of engineering activities and engineers to different levels.
- Secondly, first two levels give the possibility for making a selection of multiple systems of the third level. This selection can be used for several purposes.
- Thirdly, the levels give the possibility to the end-user to create overviews of the PRM with less detail.

Product Relation Matrix						
System part	Position	Systems				
	Block	1300 Electic Energy System		1400 Support Systems		1600 Support Systems (2nd)
	Section	1310 Main Power Generat		1430 Deck Machinery		1610 Compress gas Syste
Type	Space	13131	...	1434	....	1612	....

Figure 43 The three levels inside the Product Relation Matrix

System without functional relations

The systems of the SSWBS can be split up into several groups. The first group consists of the physical systems onboard. This group contains the 2000 to 7000 series of the SSWBS. These aspect systems contain both functional and interface relations to system parts.

The second group consists of the structural systems. Structural systems have no functional relations with system parts. Therefore the vertical columns of these systems don't contain any functional relation. The structural system defines the hull structure of the naval vessel. The hull structure is a construction set of metal parts. The metal parts of the hull structure are not defined as system part of the naval vessel. They will be defined with a number who corresponds to the part list of the construction drawing. The administration of these parts is fully performed with use of the software package Nupas Cadmatic.

However, the structural system possibly has an interface relation to a system part. An example is machinery which will be placed on a foundation. The machinery will have an interface relation to the foundation, which is a structural system. The foundation system will be registered in the Product Relation Matrix. Beside the foundation aspect system also some other structural systems need to be registered in the PRM. Examples are the Lifting Eyes and Lashing Eyes which are related to the position of accessory system parts. Lifting eyes are not registered as system part and are part of the structure of the naval vessel.

The third group contains one aspect system: the position of the system parts. That aspect system is a very important part of the PRM for definition of subsystems. A typical subsystem within engineering is the arrangement of system parts in a certain part of the naval vessel. The content of these subsystems can only be defined when there is a relation between the systems parts and the defined part of the naval vessel. This relation is laid down in the location of the system parts. The subsystems defined by the engineering documents are based on the following spatial aspects systems:

- Space: Location which defines in which space the system part is located.
- Position: coordinates which define the exact location of the system part, which will be used to relate a system part to a block or a section.

The spatial aspect system of PRM will contain block, section and space division. The different space divisions will be handled as level, similar to system levels.

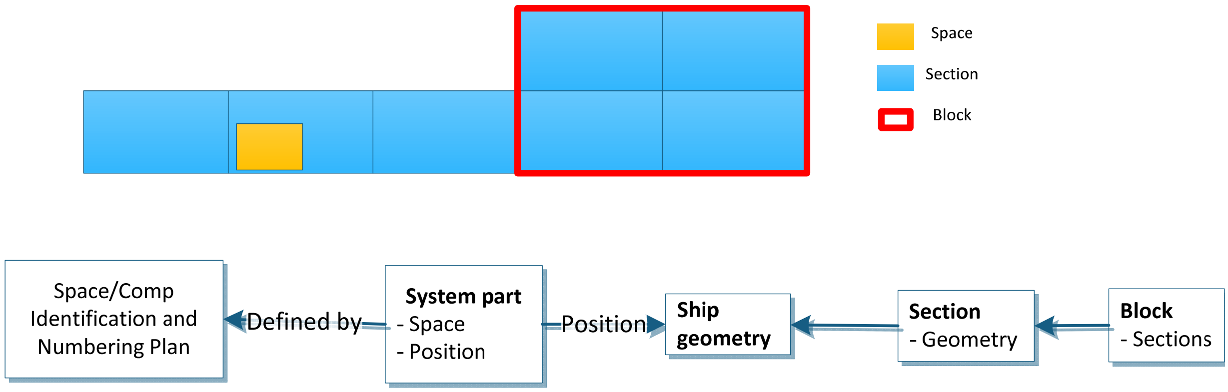


Figure 44 Spatial layout of a vessel

The WMS contains a space list containing all spaces onboard. This list can be transferred from the Product Data Management (Teamcenter) to WMS. The space list is established during the startup of the engineering project. Changes have to be incorporated into WMS, which is the responsibility of the system manager of Teamcenter. This transfer has to be in such a way that space numbers can be replaced by another number instead of delete and add of a new number.

The registration of sections and blocks will be more complicated. This registration requires the following database:

Section	Coordinates (X,Y,Z)(X,Y,Z)
Blocks	Coordinates (X,Y,Z)(X,Y,Z)

The coordinates define a 3D space which will be used for the definition location of system parts. The location of a system part is defined with the coordinates of center of gravity.

Transfer from Teamcenter

The applied SWBS is currently registered in Teamcenter, the Product Data Management. The registering of the system and spatial structure is part of the activities related to the project startup. The structure can be transferred to the WMS and registered into the PRM. However during running of the project the registered systems, spaces et cetera can be changed. Therefore an initial and every day one-way sync have to be applied between PDM and PRM. The one-way sync can result in:

- None changes.
- New system, space et cetera. The available system parts need to be analyzed for new relations between them and the new system. This analysis is a manual task which will be performed by the aspect engineer. The aspect engineer is assigned manually by the application manager.
- Existing systems, spaces will be deleted. All assigned relations to these systems need to be reconsidered by the system engineer. These assigned relations will bring to the attention of the system engineer with assignment of a task: Has the affected relation to be deleted or assigned to another (new) system?

The one-way sync implies that the data of PDM always overrules the PRM data. The data in PRM is only available for workflow management and is not leading.

The function: 'Task' of the PDL will later be defined. Due times in the Process Description Lanuguage have to be further defined with respect to adjusted procedure. The outcome has to meet with broad support of the project participants. This can involve the definition and use of different due times in the different projects.

Procedure: Sync of aspect systems

```
%%One-way sync of the systems and spaces, run daily or on request
Receive systems from Teamcenter
Compare received systems with systems in Product Relation Matrix
If new systems are received
        %%Assignment of aspect  engineer to new added systems
        Ask for assignment of an aspect engineer
        If assigned aspect engineer has none deputy
                %% Assign task to aspect engineer for registration of deputy
                Task(aspect engineer, 2 workdays, registration of deputy, …..)
        Endif

        %%Assign task to aspect engineer for analyzing consequence
        Task(aspect engineer, 2 workdays, analyzing new systems: …..)
Endif

If systems are deleted
```

List affected relations
%%Assign task to responsible engineer
Task(system engineer, *2 workdays*, analyzing affected relations: …..)
Let responsible engineer choose delete of relation or reassign to another system, whereby new systems will be bring under attention at first.
Endif

Receive list with spaces, blocks and section
Compare received data with Product Relation Matrix

If spaces, blocks or sections are deleted
List relations which are assigned to deleted spaces, blocks or sections
One-way sync of affected system parts for receiving new position
%%Assign task to responsible engineers for redefinition of engineering documents
Task(engineer of system part, *2 workdays*, redefinition of the following related engineering documents: …..)
Endif

6.1.2 Workflow flow defined by engineering activities and documents

The definition of an engineering document consists of two steps:

- Firstly, the collection of relations defines the content of the engineering document. The area is red outlined in Figure 45 and contains all available relations defined by the engineering document.
- Secondly, the product definition level of the engineering document is defined. The collection of relations in accordance with the product definition level gives the link between the engineering document and the individual relations available in the defined area of the PRM.

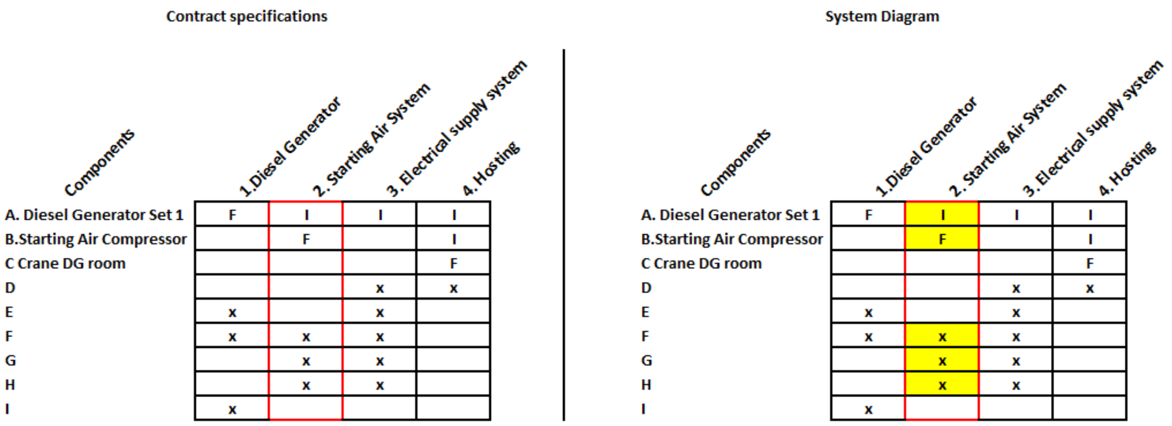


Figure 45 Selection of relations in the PRM

The collection of relations can be defined with use of the SWBS, the spatial structure and the type of system part. The selection of systems results in the definition of an aspect system. The restriction to a type of system part (machinery, electrical, appendages) or space will result into a sub-aspect system.

Product definition level

Above two-step method requires firstly available relations and secondly the possibility to link content of the engineering document to individual relations. Both requirements are not always possible. The level of the product definition inside documents differs. The system engineering approach defines the product from mission to the smallest element: the system part. The engineering documents which are describing the functions and systems of the product don't contain a description of the individual system part. Even the system parts are not defined at the moment of this document release. These documents can only be defined by an area of the PRM and further detail is not available.

> *The contract specifications will give the requirements for the starting air systems. The requirements listed for example the required starts. The individual components as for example compressor, pressure tank are not named in the contract specifications.*

The requirements are represented by the starting air aspect system of the PRM. As mentioned in chapter 5 all information has to be reflected against the individual relations of the PRM. In this case the individual relations of the starting air system. This reflection is necessary to contain the link between the requirements and all related engineering documents and tasks.

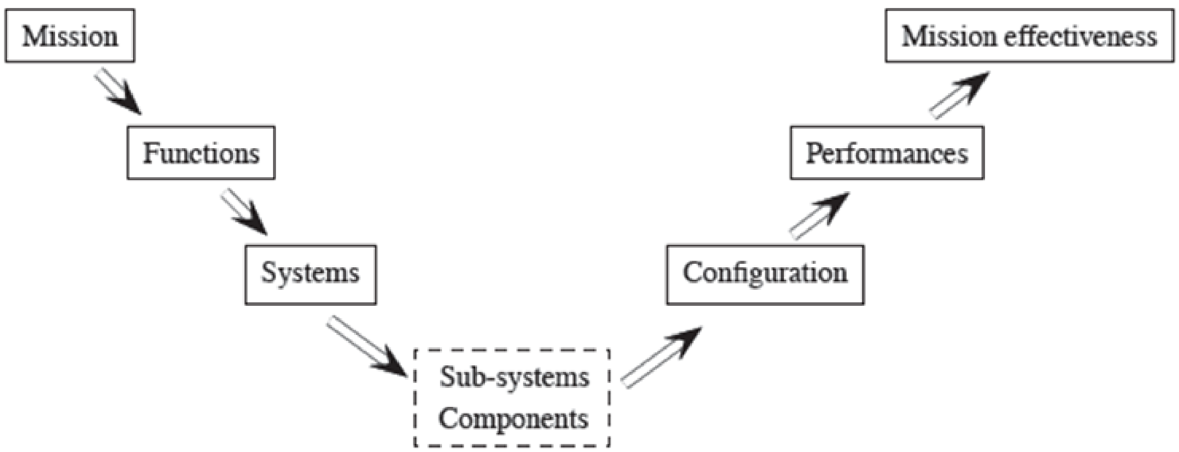


Figure 46 Level of product definition (Coenen, 2008, p. 4)

The product definition level defines the detail of the engineering document and the link between the engineering document and the covered individual relations. The following product definition levels are defined:

System level 1: The relations of the selected area are described within the document on level 1 of the SWBS. The individual relations cannot be found into the engineering document. Examples are the requirements of the contract specification which are defined on a higher aggregation level.

System level 2: The relations of the selected area are described within the document on level 2 of the SWBS. The individual relations cannot be found into the engineering document.

System level 3: The relations of the selected area are described within the document on level 3 of the SWBS. The individual relations cannot be found into the engineering document.

Relation: The relations of the selected area incorporated inside the document and an individual link between the content of the engineering document and the relations can be made.

System part: The description of the system parts inside the engineering document doesn't include more detail level for linking individual relations to the engineering document.

Item spec: The relations of the system part are specified by a group of the item specification. This product definition level will be explained later.

The product definition level will become very important for the assignment of the maturity levels to the engineering documents. The assignment of the product definition level can be performed by a right-mouse-action. The upcoming menu let the engineer choose the product definition level.

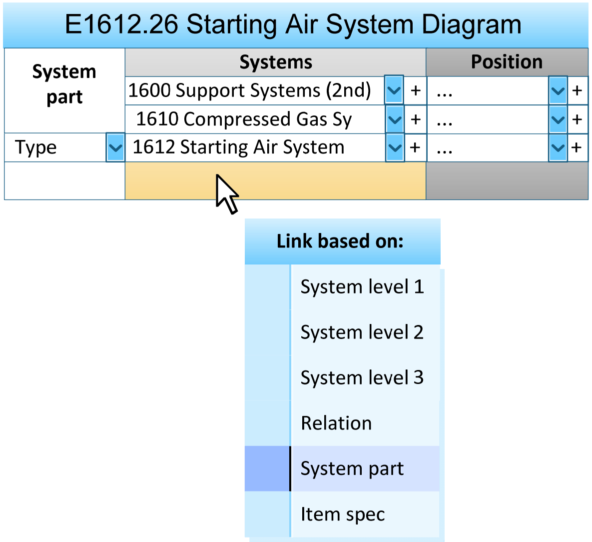


Figure 47 Product definition level

The spatial aspect system will use the same system level groups of the SWBS.

- First level is the block division
- Second level the section division
- Third level the space division.

The product definition level 'Relation' will be applied when the position of individual system parts is defined within the engineering document.

- *The outfitting drawings define the position of individual system parts and are assigned with product definition level: relation.*
- *The requirements for the engine room, part of the contract specifications is assigned with the third product definition level: space.*

This setup of the structure has not been repeated for every project. The engineering documents can be registered in a database. This database has to contain the following data:

- Area defined by the engineering document, defined with the use of the system part type, system and space.
- The product definition level of the engineering document.

With new projects the engineering document list can be setup with use of that. Beside the database also a set of rules can be applied for the document definition. Examples are the combination drawings which contain only the system parts groups: pipes, cabling, HVAC and the accessory system parts. The definition of these drawings can be performed with use of the system part ID.

Document ID	Type system part	System	Space	Assignment level
E13136.26 Starting Air System Diagram	ALL	13136,	ALL	Relations
E61130.40 COMBINATION DRAWING OF BLOCK 113 (PHASE 1)	Piping, Cabling, HVAC	ALL	BLOCK 113	Relations

Table 3 Document specification

The sequence in engineering activities

Previous chapter gives the definition of the engineering documents. The engineering documents or activities form together the engineering workflow. The steps or tasks have a defined sequence. With the implementation of concurrent engineering the engineering tasks will also be performed in parallel. The sequence of the engineering tasks is based on the engineering process, from contract specification to delivery of manufacturing information.

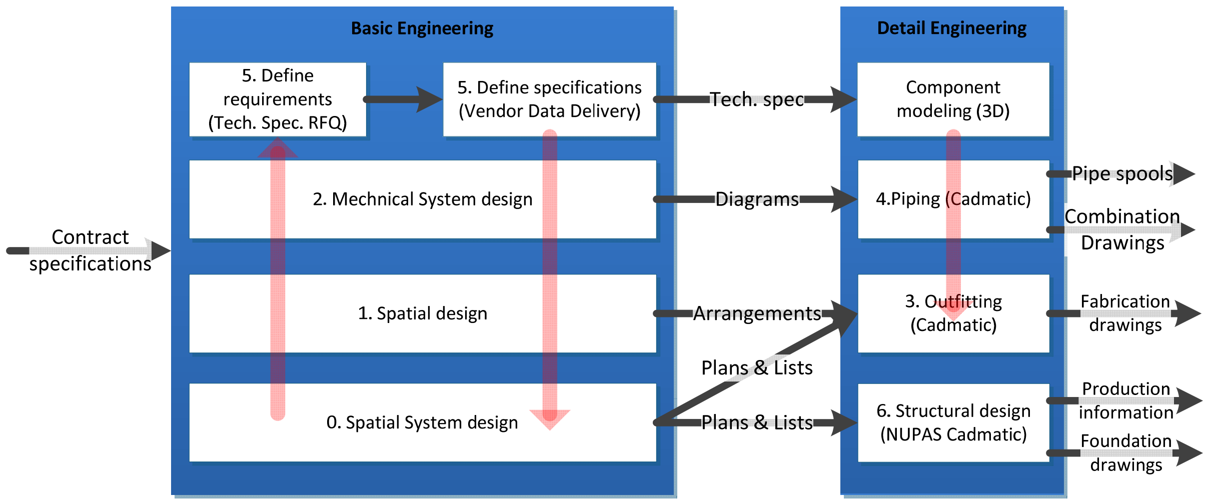


Figure 48 Process overview of the engineering process

Every engineering document has an ID which is based on the Work Breakdown Structure. The document ID is: <DOCUMENT NR>.<WBS> The WBS is a two digit code. That code will be used for positioning of the engineering document in the workflow of a relation. The sequence is based on the process model of Figure 48. The sequential steps are defined with the definition of a relation value for every engineering step, from A until H. These relation values can be used to show the progress of the individual relation.

The workflow of a relation doesn't necessary consist of all engineering activities, from A inclusively H. Some workflows will incorporate only five engineering activities. The standard engineering sequence will be implemented in WMS and the order of individual relation values can be manual changed by the document engineer.

Relation value	WBS	Description	Document	**Defined**
A		Contract specifications	DOORS document	System/Space
B	.5	Component requirements	Tech. Spec.	Item (system part)
C	.5	Vendor Data Delivery	Tech. Spec.	Item (system part)
D	.2	Mechanical System design	System Diagram	System
E	.1	Spatial design	Arrangements, Plans	Space

F	.o	Spatial system design	Structural arrangements	Ship structure
G	.19	3D Component modeling	3D CAD	Item
H	.3 .4 .6	3D CAD modeling	Fabrication drawing Combination drawings, Pipe spools Production information, Foundations drawings	Block Block Block

PDL

Above procedure results in the following PDL:

Procedure: Document definition

%% Document definition performed for every new engineering document

Determine type of document with use of Document ID

%% Relation selection
Ask for selection of systems of the SWBS
Adjust selected relations area
Ask for space selection
Adjust selected relations area
Ask for system part group selection
Adjust selection area

%% Product definition level selection for document
Let user select product definition level

%% Assign project participant
Let user select document engineer of list of Team Leaders or Chief Engineer
If assigned document engineer has none deputy
    %% Assign task to aspect engineer for registration of deputy
    Task(aspect engineer,2 workdays, registration of deputy, …..)
Endif

6.1.3 Registration of the different type engineering documents

In this paragraph the document and activity groups (A till H) of the Work Breakdown Structure will be separately described.

Contract specification (A)

Paragraph number	SSWBS
Chapter 0	0000 Guidance and Administration
Chapter 3.1	3100 Electric Power Generation
Chapter 5.3	5330 Fresh Potable Water System

SSWBS	Subsystems
0000 Guidance and Administration	0000-0999
3100 Electric Power Generation	3100-3199
5330 Fresh Potable Water System	5330-5339

The contract specification is describing the naval vessel. The contract specifications are organized according the SWBS. Chapter zero defines some overall specifications and global specification of (physical) systems. The following chapters define the systems of the naval vessel in more detail. The contract specifications can be linked to the Product Relation Matrix with use of the definition of aspect- and subsystems. All specifications according systems can be linked directly to the defined aspect systems, using the SWBS.

The contract specification is also handling specifications which are related to special parts of the naval vessel, for example the aft deck or helicopter platform. These specifications can be linked to defined subsystems. The subsystems are defined according the space list, set up with use of the General Arrangement Plan.

Technical Specifications of items (B,C)

The Technical Specifications are based on items, the smallest specified component for procurement. Every system part is linked to one item, but one item is linked to one or more system parts. For example every door on board has a unique system part number, also in case of similarity between five doors. The similar doors are defined by one item number.

The technical requirements and specifications are defined using the item number. However these technical requirements can be easily connected to the accessory system part number. Therefore the first step of relating technical requirements and specifications to system parts is incorporating the item numbers in the database of the Workflow Management System.

The technical specifications are managed by the new developed Vendor Data Delivery Schedule (VDDS). VDDS is a tool which controls the process of receiving technical specifications. The items are incorporated and assigned to subcategories. The subcategories of VDDS are not similar to the aspectsystems of SWBS.

One item is connected to one or more system parts, and therefore an item specification is valid for several system parts. The supplier however is interested in the required specifications and is not interested into the different functional and interface relations of the five delivered pumps. An example will explain this:

Five pumps are ordered by one supplier. The 11^{th} VDDS aspect system requires the definition of the flow characteristics. The five pumps are part of five different SWBS aspect systems. The supplier delivers the flow characteristics which valid for all relation values of the five functional relations of SWBS aspect systems.

A solution is creating a link between the VDDS aspect systems and the SWBS aspect systems. This requires a one-time action and can be used within every new engineering project.

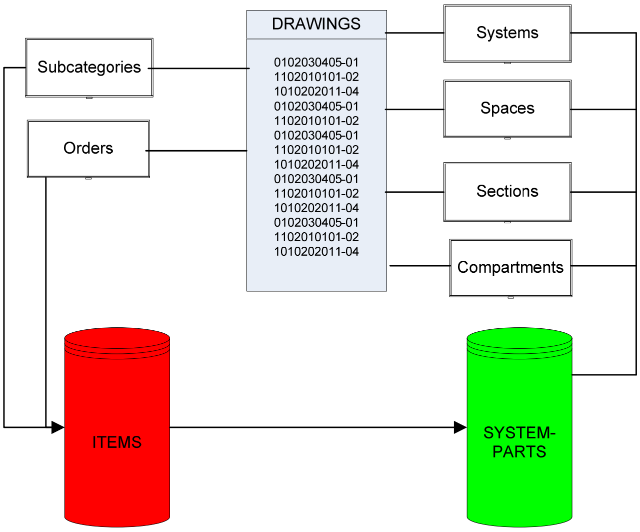


Figure 49 Data overview

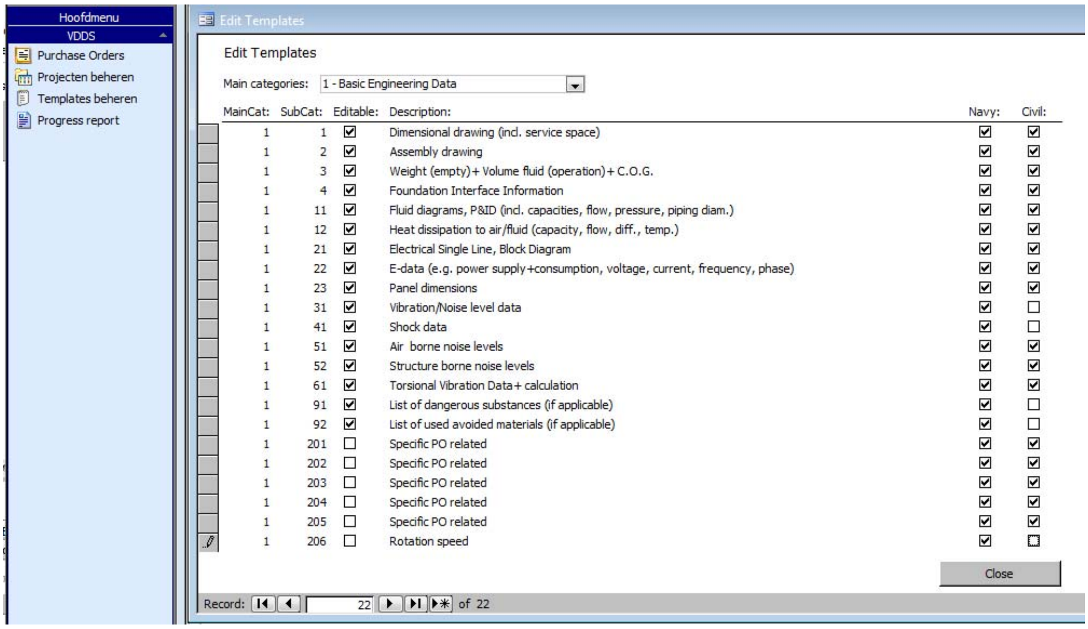


Figure 50 Subcategories in the VDDS tool

So for every VDDS subcategory of an item an applicable sub-aspect system is defined of the PRM:

1. Aspect system definition: Define the linked SWBS aspect systems for every VDDS subcategory system.
2. Subsystem definition: Enumerate related system parts of an item.
3. Relations inside the defined sub-aspect system are linked to a subcategory of an item.

System diagrams (D)

The system diagram defines the mechanical design of a system. The engineering document contains all related (functional and interface) relations of the described aspect system. The link between the engineering document/activity will be based on the fourth level of the aspect system.

Plans (E)

A plan is a spatial overview of one or more system. The engineering plan can contain the individual system parts, but usual the plan is defining the requirements on a higher level for a certain system. An example is the Fire Integrity Plan of chapter five. The engineering plan is a step between the contract specification and the design on system part level. The specification of the contract will be combined with the international vessel rules, product standards of DSNS and gives direction to the following design process. The engineering plans are approved by the classification society.

Arrangements (E)

Arrangements display the spatial design of the vessel. The arrangements drawings describe a subsystem of the vessel. The subsystem is defined by a space, section or block. The subsystem can further narrowed by the restriction to a type of system parts. An example is the restriction for displaying only piping, appendages and ducting. This restriction can be defined with use of the filtering of the system parts on type.

3D CAD model (G,H)

The 3D CAD model combines a selection of system parts and the hull structure of the naval vessel. The assignment level of the 3D CAD model will be on system part level. The system parts will be modeled and placed inside the vessel model. The 3D modeling of the system parts will be defined as a separate engineering task. The separation into 3D modeling and placement inside the 3D vessel model is based on the assignment of the two tasks to different engineering participants.

Actually the 3D modeling of the system parts is the modeling of the items of the project. Therefore the 3D modeling of system parts will get the item specification assignment level. As mentioned the system parts inside the vessel model are a selection of all system parts of the naval vessel. Small system parts will not be visualized in the 3D CAD model. Therefore for every item the 'visualization in CAD' is registered in PDM, which is part of the current procedure.

Production drawings

Production drawings are released to work preparation or the shipyard. With the implementation of manufacturing engineering the production drawings could be replaced with digital or printed manufacturing instructions. The Product definition level is: system part. The area of the production drawings is defined according blocks, sections or spaces.

6.2 Relation registration

The previous paragraph shows the setup of the Product Relation Matrix, and in particular the definition of the aspect systems and engineering documents. Within this paragraph the registration of the system parts and accessory relations will be defined.

A system part is a unique component of a naval vessel. It's the lowest level component which is controlled separately. The System Part ID has the following structure:

<PROJECT><SYSTEM><S><XXXX>

PROJECT:	A unique letter combination defining the project
SYSTEM:	Functional relation of a system part to one system of the SWBS
S:	Character which defines the kind of system part. There are different groups defined as machinery, electrical, appendages et cetera.
XXXX:	Denotes a unique number

The system parts are first registered in Teamcenter, the Product Data Management of DSNS. The system part code defines the functional relation of the system part. The definition of the relations of a system part will consist of two steps:

- Firstly, the transfer of the system parts from PDM to PRM and the registration of the functional relation of each system part. The functional relation can be derived from the System Part ID.
- Secondly, the definition of the interface relations. This will be performed by the system engineer.

The relation ID is based on the aspect system and system part:
<ASPECTSYSTEM><-><PROJECT><SYSTEM><S><XXXX><'-'><R>

ASPECTSYSTEM:	SWBS number of the aspect system.
R:	Character F or I which represents Functional or Interface relation.

When the relations and engineering documents are registered, the workflow can be defined. The workflow becomes the defined engineering activities applied to one relation.

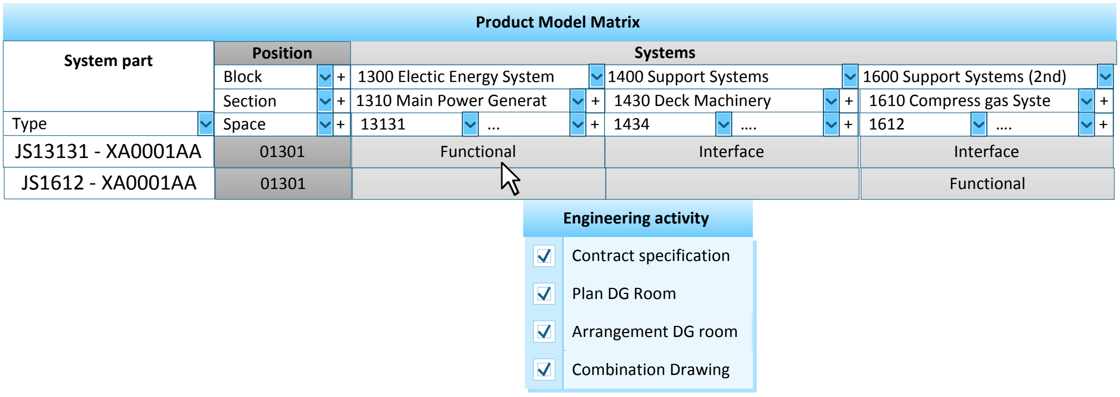


Figure 51 Registrations of system parts and relations in the Product Model Matrix

The initial registration of the interface relations by the system engineers will not comprise all interface relations. Firstly, during the design relations between system parts and systems are add, as part of the system integration. These new interface relations can be discovered by comparison of the system part list of the document with the registered relations in the PRM.

The system diagram of the starting air system is defining all functional and interface relations of the starting air aspect system. All system parts which are part of this engineering document have a relation to the starting air system. Almost all these relations are already assigned during the specifications of the system parts by the system engineer. However during design the engineer finds another system part, which has a relation to the aspect system. This system part will become part of the system diagram and is included into the system part list of the system diagram.

The extra added relation is not found without extra analysis. These relations can be found with analysis of the system part list of the document. With uploading of the engineering document these list has to be compared with the database.

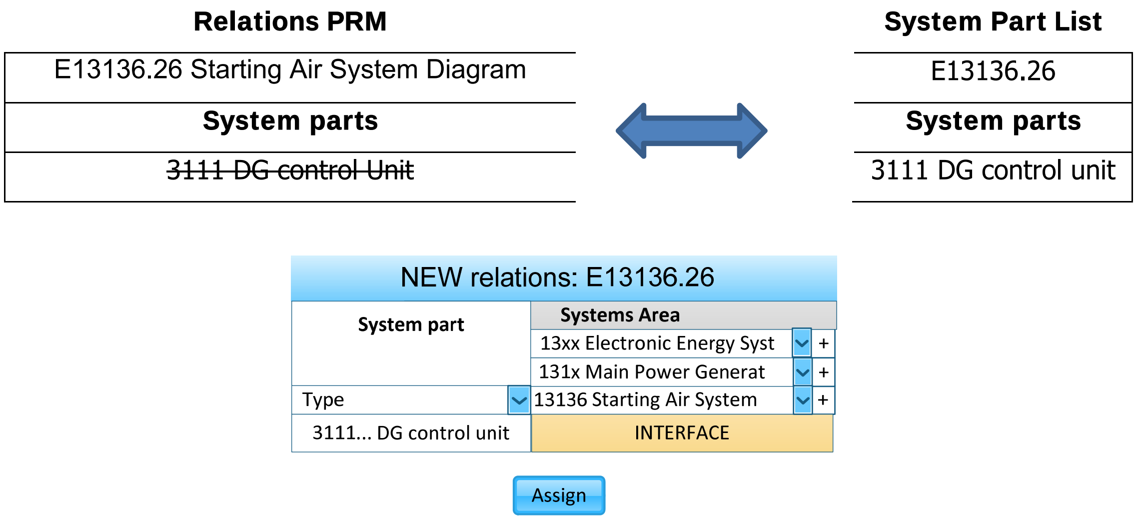


Figure 52 Assignment of new relations to system parts

Secondly, the system engineer is not always be able to define all interface relations. The system engineer supposes extra interface relations, but doesn't know the exact relation of that system part to a specific system. In this situation the system engineer will assign a task to another project participant, probably an aspect engineer, with the request for analyzing the system part for extra interface relations.

Above procedure results in the following PDL:

Procedure: Registration of system parts and relations

Receiving system parts from Teamcenter

If new system parts are received by WMS from PDM Teamcenter
- Register functional relation of system part according the system part ID
- Assign system part to the system engineer
- Gives the system engineer the possibility to assign task to an aspect engineer
  - **Task**(aspect engineer, 2 workdays, registration of relation, system engineer)

Endif

If document will be saved to Teamcenter
- Compare system part list with relations assigned to document in PRM
- If new relations in document are found
  - Ask engineer for agreement of new relations
  - List other documents of new relation with product definition level: system part
- Endif

Endif

Notify assigned engineers of these documents about new relation

```
        If none engineer is assigned
                Notify document engineer
        Endif

Run procedure Maturity level selection
```

6.3 Roles and Authorizations

Roles

The Workflow Management System requires the definition of a set of roles which are responsible, accountable or informed during the project process. One person can perform multiple roles in a project team. The following roles and registration moments are defined in the Workflow Management System:

- Firstly, for every added system to the PRM an aspect engineer is assigned, which is accountable for one or more aspect systems. Usually the role of aspect engineer is performed by a Team Leader. The Team Leader is with his team responsible for the engineering of a number of systems. The numbers of systems are usually determined by the SWBS structure. The assignment of a Team Leader to a system is a task during setup of the PRM.
- Secondly, for every added system part in to PRM a system engineer is assigned. The system engineer is responsible for all relations of this system part. The project participant which performs this role is defined with use of the grouping of system within purchase orders. This grouping is performed with use of the item structure, which is covering all system parts.
- Thirdly, every added engineering document will be assigned with a document engineer. The document engineer is always a Team Leader. This is in accordance with current procedure. The Team Leader is responsible for the engineering document and performs the checks on the document. The Team Leader is being able to assign engineering documents to an engineer. If the Team Leader is unknown the Chief Engineer can be registered as document engineer and in a later moment being replaced by a Team Leader.
- Fourthly, the Engineer which edits the engineering documents. The engineer is responsible for an engineering document and all its relation values. The engineer is allowed to create system parts and functional and interface relations. Furthermore the maturity levels of relation activities may change from unworked to preliminary and final.
- Fifthly, the subscriber who is a project participant who wants to be informed about certain relations. The sign up to several relations will be performed by themselves. The subscriber cannot influence the relation by himself.

- Finally, the application or facility management will be performed by the Data and Information department, which is responsible for the Product Data Management system and other engineering software.

RACI chart **R**: Responsible **A**: Accountable **S**: Supported **I**: Informed **Procedure step**	Chief Engineer	Document engineer	System engineer	Aspect engineer	Engineer	Subscriber	Application manager
Setup of the product information matrix	A		R				S
Maturity level: Preliminary and Final		A			R	I	S
Maturity level: Approved	A	R				I	S
System part registration		A	R		R	I	S
Relation registration		A	R	R	R		
Starting EC procedure		A			R		

Table 4 Overview of the roles and the authorities of the relation activities and maturity levels

Registration of an user

The assignment of roles to project participants, called users, is done during project startup as well as during the whole project. The roles of project participants define the authorizations of them. The assignment of project participants will be in accordance with one important rule: the procedures applied during engineering require the assignment of minimal one project participant to an engineering document, system part or other object.

Registration of a user requires at first a complete profile, consisting the following elements:

- The function of the user, which defines the possible roles of the user in WMS and prevents incorrect authorizations.
- The registration of a deputy in case of absence of the user. The deputy is not always known before startup of the project. Therefore several procedures have implemented a check which checks the availability of a deputy. If no deputy is registered a task is assigned to the user which requests the registration of a deputy.
- For every user an executive is defined, which is usually a Team Leader. The Team Leaders are known with startup of the project and ensures the availability of a deputy for the user.
- E-mail address of the user. This will be very important for the assignment of tasks to the user. This e-mail address needs to be verified by the user. This is required for prevent incorrect addresses in case of external users as for example subcontractors.

Above information will be saved in a database and can be extended with data about the assignment of tasks, roles and authorization of the users.

6.4 Validation process of documents and relations

Relation value A	Unworked
	Preliminary
	Final
	In check
	Approved
Relation value C	Unworked
	Preliminary
	Final
	In check
	Approved

As mentioned in chapter 3 concurrent engineering requires the use of preliminary information. The maturity level of the engineering information indicates the reliability of information. The maturity level of information is not equal for all relation values at a given moment, consequence of the iterated character of the engineering process. Therefore the maturity level of information has to be defined for every relation value.
The engineering documents capture a collection of relations values. The detail of the maturity level is denoted by the product definition level of the engineering document. An engineering document will be assigned with one maturity level in case of capturing one first level system of the SWBS A maturity level for every system part is assigned if the document has the system part definition level. The consequence for this appliance of maturity levels will be explained with the following examples:

The Starting Air System Diagram is linked to a starting air system diagram. The links to the collection of relations is based on the fourth level: system part. All relations contained by the engineering document have an individual maturity level assigned. The compressor of the system can be assigned with another maturity level as the pressure vessel of the system.
The client requirements for the starting air system, part of the contract specifications, have the third assignment level. The client requirements therefore are assigned with one overall maturity level, covering all listed requirements.

The maturity level will be denoted by four levels, and will be extended with two maturity levels with the implementation of engineering change management. The first maturity level is 'Unworked'. Unworked defines the existence of a relation inside an engineering document.

This is the case at the start of engineering. The system engineering denotes the functional relation of the air compressor to the starting air system and assigns the functional relation to the starting air system diagram. This engineering document is *already defined but unworked at that moment. The maturity level of the functional relation is unworked.*

The second maturity level is 'Preliminary'. This maturity level will be colored with red in the matrix. The relation value is not be reliable or complete and can only be used for estimation and assumptions by other engineering activities.
The following level is 'Final', which has the orange color. This level indicates the reliability of the relation value as finalized. However the relation is not checked or approved according ISO 9001. The highest maturity level will be reached by the 'Approval' of the relation, where after the relation gets the green color. The relation value will be approved during the document approval, which is part of the document validation process.

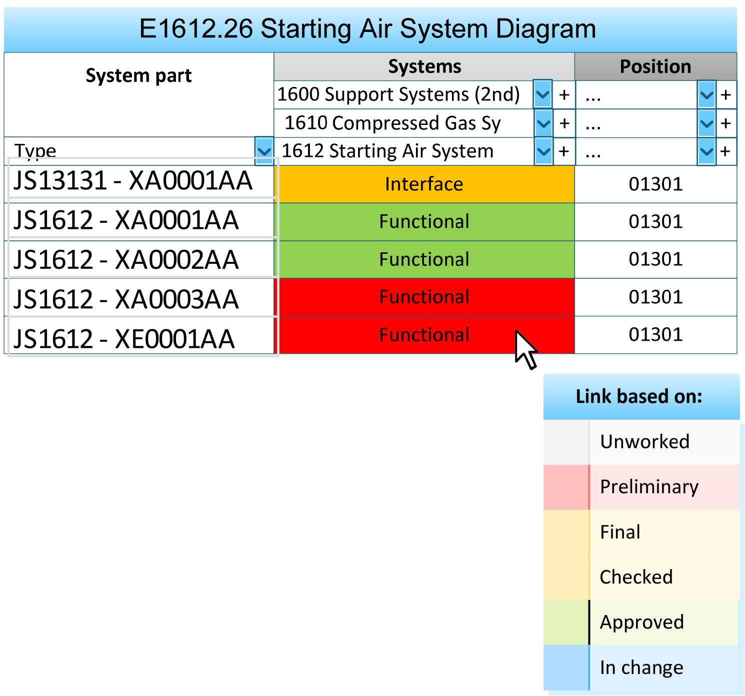


Figure 53 Assignment of the maturity level

Current document life-cycle is different to the defined maturity levels. It's recommended to adjust current document life-cycle to the relation life cycle to achieve uniform terms. However there will be a major difference between the relation validation and document validation procedure. The approval of documents means the approving of all final relation values inside the document. The approval doesn't tell anything about the other relation values inside the document. The approved relation values will be frozen and can only be changed by an engineering change procedure.

Procedure: Maturity level selection

<u>%% Assignment of the maturity level to relation values</u>

If document will be saved to Teamcenter
    Ask for changes in maturity level of document content (relation values)
    Ask maturity level of new relation values in document
Endif

If document will become 'in check'
    Ask for changes in maturity level of document content (relation values)
    Ask agreement and notify the user that only final relation values can be checked
Endif

If document will be checked by document engineer
    Ask agreement for changing maturity level 'final' in 'checked'
    Give user the possibility for partly agreement
Endif

If document will be approved by chief engineer
    Ask agreement for changing maturity level 'checked' in 'approved'
    Give user the possibility for partly agreement
Endif

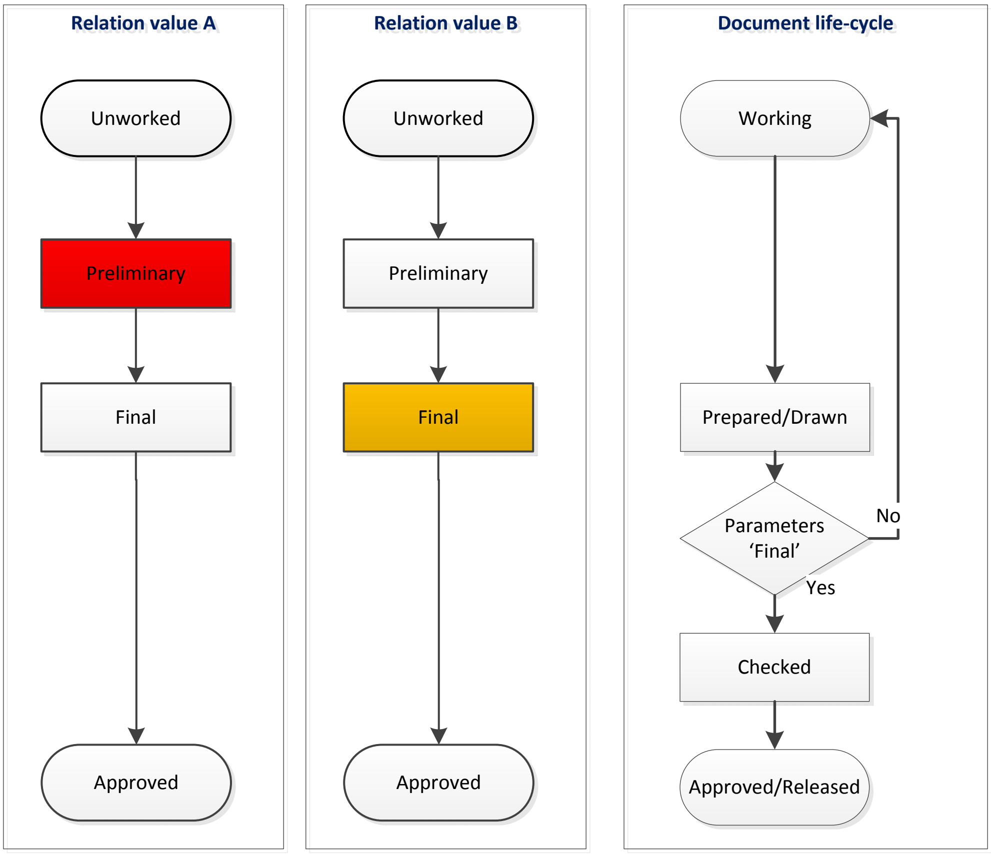


Figure 54 Relation value life-cycle versus the Document life-cycle

Manufacturing Engineering

The Manufacturing Engineering, State H and the accessory Detail Engineering of State G are using the 3D CAD product model. As noted in Chapter 2 the 3D CAD product model can get a bigger role as final communication and exchange tool to the shipyards. The missing 2D drawings require the implementation of a validation process inside the 3D CAD software. After approval of the relations inside the 3D CAD model the relations can be released with 2D drawings, with 3D instruction et cetera. Therefore relation value H needs one extra maturity level: 'Released'. The maturity level 'Approved' can therefore be used to approve the relations inside the 3D model and there after the release of Manufacturing Information, in any possible form can be indicated with the maturity level indicator 'Released'.

Check for reliability

The relation values have all their own maturity level. To ensure the reliability of information the following rule can be introduced. The maturity level of a succeeding relation value can only have an equal or lower maturity level as the previous one. However this rule will prevent parallel engineering activities and is therefore not desirable. Parallel engineering is not sequential and therefore the relation values are not defined sequential.

The rule for reliability can be implemented as check for reliability. This check will give an overview of the reliability of information which can be further analyzed. The check will be based on the following mathematical rule:

M_i:= maturity level of relation value i.

$$M_{i+1} \leq M_i$$

This rule will check the assignment of a maturity level, which is based on a lower maturity level in a previous relation value. Figure 55 displays an overview of the possible combinations of maturity levels on the different relation activities.

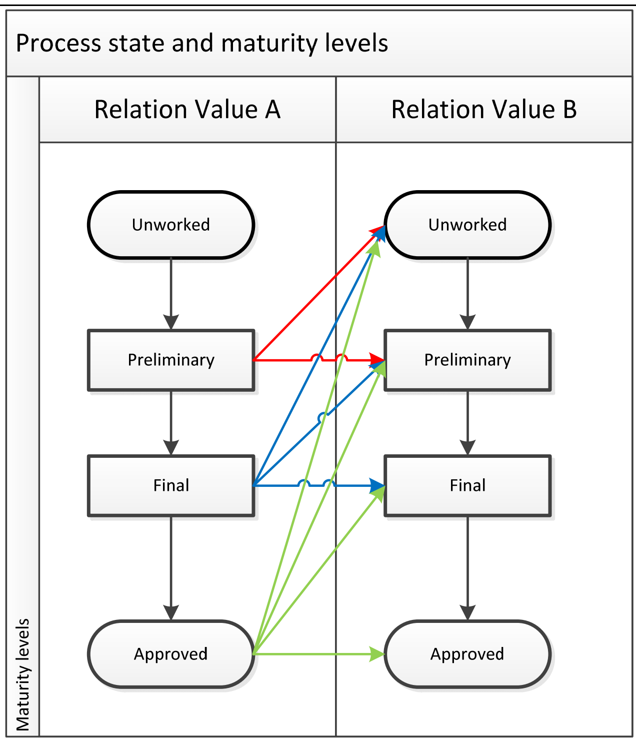


Figure 55 Maturity levels on the different relation activities

6.5 Engineering change management

The design of the naval vessel is an iterating process. Even approved engineering information is subject to engineering changes. The Workflow Management System gets an important role in the engineering change procedure.

6.5.1 What is changing?

The engineering change procedure starts when an approved relation value will change. As mentioned the product definition level of engineering documents differs. In case of the first product definition level, it will become difficult to assign the engineering change to one relation value. These documents will describe a whole system and no more detail about the content of the engineering document is administrated inside the PRM. An engineering change in these documents has to be manual reduced to one or more relation values if possible. This reduction to a set of relation values will decrease the analysis of the engineering change propagation.

After notation of the changing relation value, the maturity level of relation value has to be read out the PRM. The change of unapproved relations ('Preliminary' or 'Final') will have no consequence for the engineering process, and the change propagation will not be further investigated. The engineering change will be communicated with use of the messages 'updated' or 'changed'. These notifications are sent to all project participants linked to this relation. This relation value change is part of the concurrent engineering approach and will be seen as the update of preliminary information.

Procedure: Check engineering change request

%% Check if the engineering change request applies to the requirement: the changing relation value has to be approved.
Let user select relations values which will initiate the EC procedure
Perform procedure: **Check overlap (with another EC procedure)**
Check maturity levels of selected relation values
    If the relation values is maturity level is 'Unworked', 'Preliminary', 'Final'
        Show the dialog box containing the following text: "The maturity level of this relation value prevents being an initiator of an engineering change procedure. Take contact with the document engineer"
    Endif

With the start of the EC procedure also overlap with other running EC procedures has to be checked. Firstly, this will prevent the starting and running of two EC procedures by two project participants which covers the same engineering change. Secondly, overlapping EC procedures may get merged to prevent two parallel problem solving processes which are independent to each other.

Procedure: Check overlap (with another EC procedure)

%% Prevents the starting of an EC procedure which is about relation values which are already in change by another running EC procedure.

If one of the relation values is already in change
    Notify the user about the overlap with the another EC procedure
    Assign the EC procedure to the aspect engineer which become user
    Task(aspect engineer, 1 workday, merging of EC procedures, initiator of EC procedure, Merging EC procedures)

    Let aspect engineer choose between merging or continue
    If user choose for merging
        Send merging request to initiator of overlapping EC procedure
        merge both EC administrations
    Else continue engineering change procedure
Endif

6.5.2 Change propagation

The second step is the determination of the change propagation in case of an 'Approved' or 'Released' relation value. The first step will be changing the maturity level to 'In change'. The relation value will become part of the engineering change procedure. The engineering change will be administrated as:

<'EC'><RELATION ID><P><XX><CP>

EC represents Engineering Change.

RELATION ID is the defined relation identification code.

P represents Process state and defines the relation value.

XX is the sequence number in case of more engineering changes is applied on to one relation value.

CP indicates the position of the change relation in the change propagation.

The interface relation value of the DG Set of the starting air system is changed. The engineering change is defined as: EC-13131XA0001AA-1612-I-D-01-00 which stands for:

- *system part ID of the DG Set*
- *the 1216 starting air system*
- *INTERFACE relation*
- *First engineering change onto this relation 01*
- *00 indicates the source of the engineering change*
- *Relation value D: System Diagram is changing*

The first step of the EC procedure will ends with the request for approval to the aspect engineer. The approval will start the EC procedure.

Procedure: Start the engineering change procedure
Setup EC administration with assignment of EC number Add relation value to the EC list with following code: <EC><RELATION ID><P><XX><00> Ask EC description of user containing: - Origin (Engineering, Supplier, Subcontractor, Client, Class) - Description of the EC Ask for other initiating relation values Ask for due date of the EC procedure %% Request for agreement of starting EC procedure to aspect engineer Perform function: **Task**(aspect engineer, 1 workday, approval of starting EC procedure, initiator Ec procedure, EC procedure) If EC procedure approved by aspect engineer Perform function: **EC propagation** Endif

Engineering change propagation

The following step is determining the direct change propagation. The direct engineering change propagation can be system part based or aspect system based. In the first case propagation to other relations of the affected system part and in the second case propagation to other relations of the affected aspect system. Dependent to the involved engineer the direct change propagation can be determined by itself (marked as 'In change') or the relation will be marked as 'Check for change'. 'Check for change' will assign a task to the linked aspect engineer to decide if the relation will be affected and has to become 'In change'. The aspect engineer is authorized to decide the change propagation for the relation values. The aspect engineer is be able to assign this task to the document engineers of the relation values.

Procedure: EC propagation
Make list: relation values in change Make list: relation values check for change Make list: relation (values) not in change Make list: relation value in check by engineer Add initiating relation values to list: affected relation values List possible affected relations

If affected relation is not on list: relations (values) not in change *%%Prevent recurring loop*
add them to list: check for change
Endif

While list: relations values check for change = not empty
Group relation values on list by relation
Assign task with Function: **Task** (aspect engineer,1 workday, Check relation for change, WMS, initiator EC procedure) *%% Analysis of the affected relation values by assignment of the relation to an aspect engineer which decided if all responsible users of the individual relation values has to decide if the relation values will become in change*

Aspect engineer can choose between:
1. relation (values) will not change
   Add relation values to list: not in change
2. relation (values) will be affected and become in change
   Add relation values to list: relation values in change
3. relation value has to be assigned to engineer
   Add relation value to list: relation value in check by engineer

If list: relation value in check by engineer = not empty
Function: **Task** (engineer, 1 workday, Check relation value for change, WMS, initiator of EC procedure)

Engineer can choose between:
1. relation value becomes not in change
   Add relation value to list: not in change
2. relation value will be affected and become in change
   Add relation value to list: relation values in change

Endif

List possible affected relation values from aspect system or system part
If affected relation value is not on list: relation (values) not in change
add them to list: relation values check for change
Endif

Report daily progress of EC procedure to initiator of procedure

Affected relations are listed with list: relation values in change
Notify initiator of the EC procedure about finishing of change propagation analysis
Function: **Task** (initiator EC procedure, 1 working day, plan meeting with all users affected by the EC, WMS, Initiator)

Starting Air System		
System part	**DG SET**	**Pressure Tank**
Functional membership	Diesel Generator System	Starting air
Contract spec	DG System	Starting air
Tech Spec	Flow diagram DG Set	Flow diagram Pressure Tank
Plans		
Diagrams	Starting Air	Starting Air
Arrangement		
Outfitting drawing		
Positioning		

Setting:
In change
Check for change

Figure 56 Dashboard for the assignment of indirect engineering changes by the engineer. Relation values in change are yellow.

Preventing recurring loop

A risk of the engineering change procedure is the recurring loop or the repeatedly asking for 'check for change' of a relation value. This can occur when relation values will have multiple relations to other relations which will become 'in change'. The engineer gets multiple requests to check for change. This can be prevented by the implementation of an extra list. This list will contain all relation values which are already checked and which will not change. This list will prevent for repeatedly request to engineers.

However this list will also limit the performance of the engineering change procedure. The relation value can become in change as consequence of all related relation values. Therefore a first check will not exclude any change by another relation value. In practice the application of the WMS will point out which will be the best choice for the engineering process.

Visualization

Figure 57 gives a visual overview of the engineering change procedure. The relation B4 has been changed. The direct change propagation can be caused by the affected system part or the affected aspect system (blue color). Within the product matrix the two change propagations can be colored with a horizontal and vertical bar. Relations which require change gets the maturity level 'In change' and will be the new input for this engineering change process.

The third step is the search for indirect change propagation, or the direct change propagation of the parameter values D4 and B3. The engineering change procedure will stop if no new change propagation can be found.

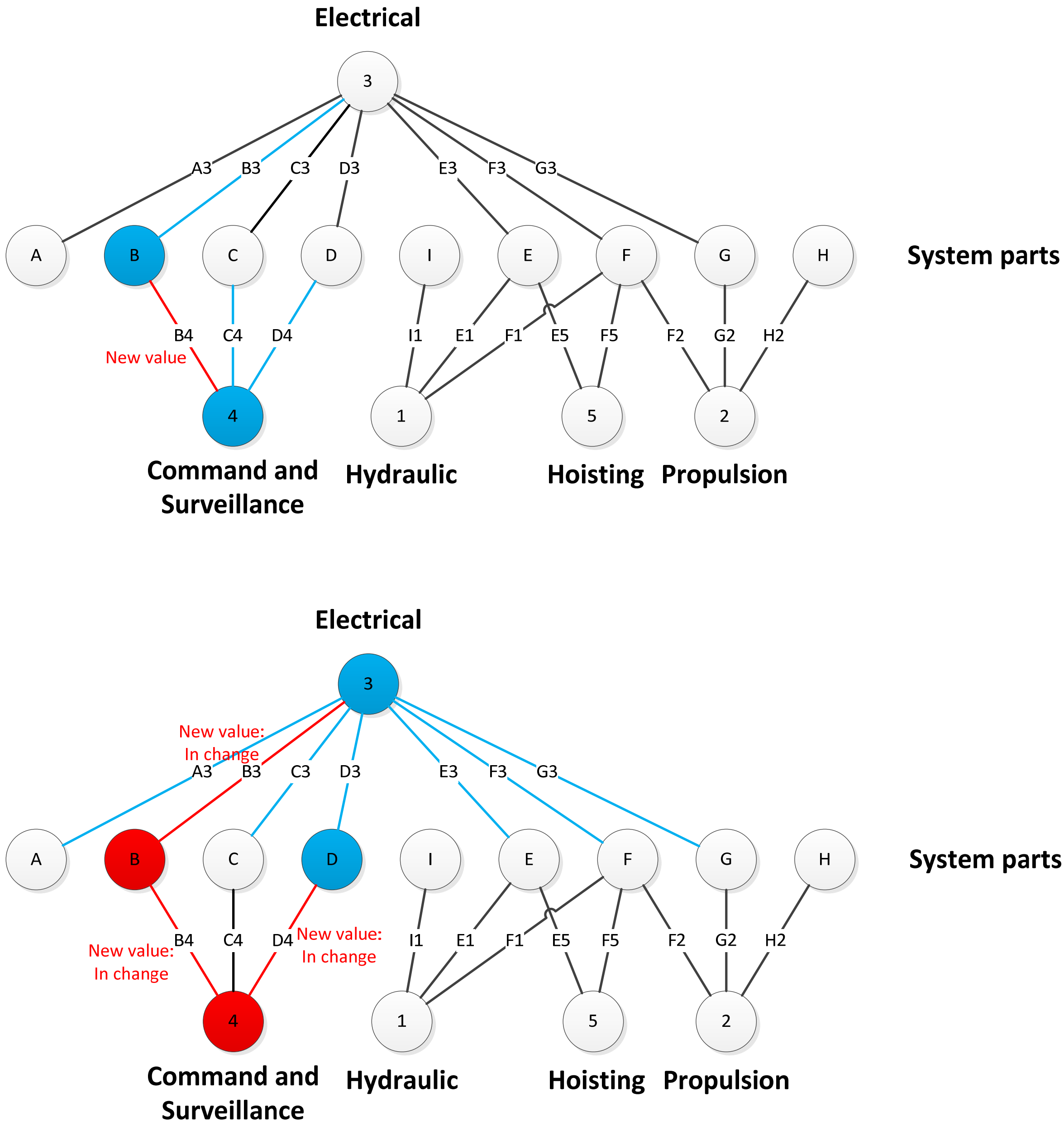


Figure 57 Parameter change procedure displayed within the parameter network

Meeting request

The fourth step is listing all affected relation activities. Therefore the structure has been displayed in Figure 58. The engineer who is starting the engineering change procedure is responsible for organizing a meeting to discuss the implementation of the engineering change. The software will be equipped with a connection to Outlook, whereby the engineer is able to schedule a meeting with all involved project participants. The invitation is sent to the group engineers with as subject: EC-13131XA0001AA-1612-I-01-00. At the meeting the engineering change will be discussed and the engineers will implement the engineering change. The relation activities will become 'Revised'.

Meeting request		
Engineering change ID	**Relation value**	**Project participant**
EC-13131XA0001AA-1612-I-01-00	*13131XA0001AA-1612-I-D*	Jan
EC-13131XA0001AA-1612-I-01-01	…….	Piet
EC-13131XA0001AA-1612-I-01-02	……	Marco

Meeting request

Figure 58 Making meeting request

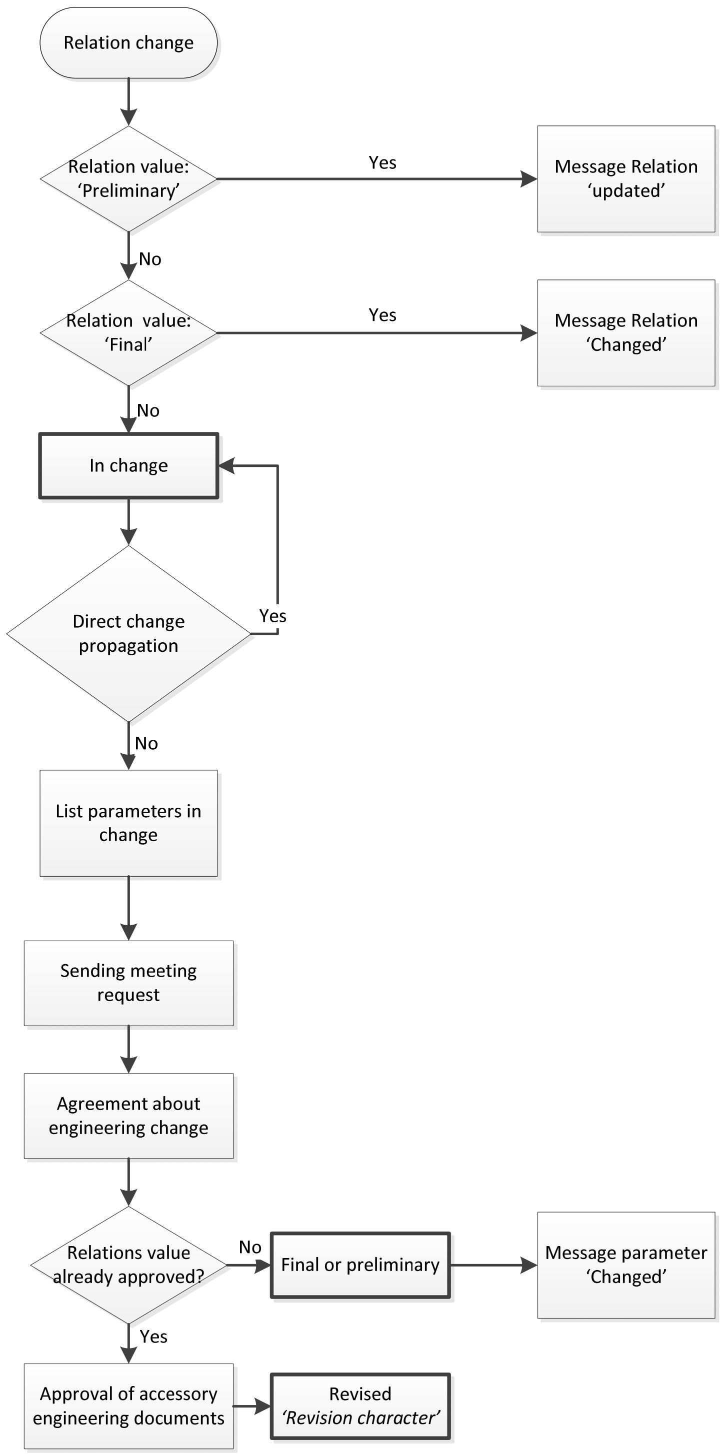


Figure 59 Engineering change procedure

Document revision

The engineering change procedure results in revised engineering documents or 3D CAD models. This revised information will released and applied with a revision character. The revised engineering document has to be linked to the revised engineering activity. This is necessary in order to trackback the document revision and to communicate the engineering change to other engineers.

A revised relation value will be assigned to a revised engineering document. This assignment will be applied manually by the engineer and will be part of the engineering change procedure. The structure of this administration can also be used to identify the revised content of an engineering document. The revised content of an engineering document can be listed with filtering all relations revisions to the revised engineering document.

Document ID	Date approval
JSE1612.21	15-01-2012
JSL13131.60	10-09-2012

Engineering change ID	Document ID
13131XA0001AA-1612-I-01-00	JSE1612.21
13131XA0001AA-13131-F-01-00	L13131.60

In2CRM export

In2CRM is the software packet for communication of engineering changes to the shipyard. The engineering change is described, linked to an engineering document and sent to the shipyard. With the Workflow Management System the description, linking can be performed by WMS. The shipyard can become subscriber of relations. With filtering to relation values defining production the shipyard will get automatically a notification if a relation will be 'In change' and is be able to anticipate on upcoming engineering changes. The anticipation can set related production activities on hold to wait for the revised production information.

6.6 Structure of the Workflow Management System

Implementation in current data structure

The Workflow management will be implemented beside other implemented software and management systems. Also other data will be linked to the Workflow Management System. Within this paragraph an overview is given about the data relations, which are displayed in Figure 60.

.

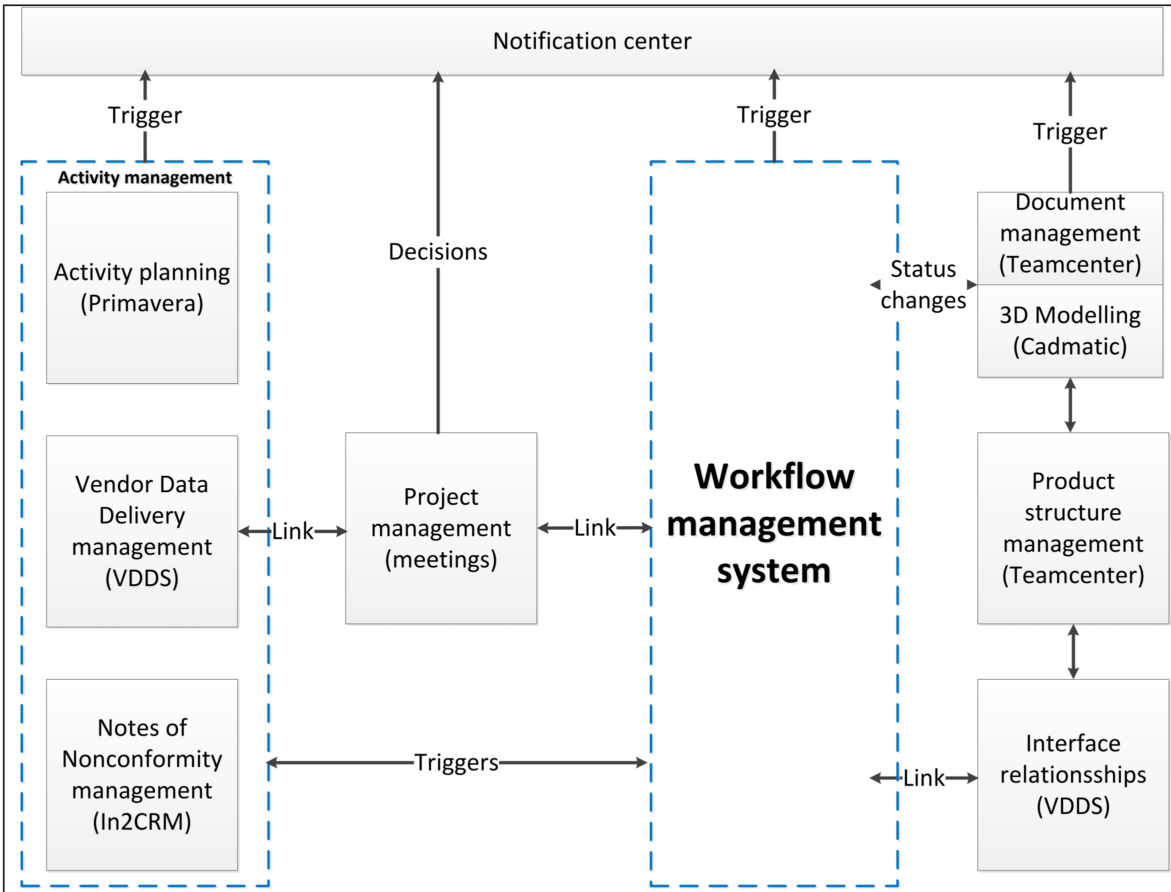


Figure 60 Data structure of Engineering (change) management

As mentioned in chapter five many other information according the engineering process can be incorporated in the Workflow Management System. For example the minutes of meetings of the project meeting.

DSNS has in global three types of meetings. At first the Team Leader meeting which is a meeting of all Team Leaders with the project manager. As second the technical meetings, which are mostly discussions about the technical issues with client or subcontractor. The third are the meetings with customer about the progress of the project, desired product changes et cetera. These three types of meetings, added by the normal communication on the work floor, will result in many separate minutes of meetings. In three minutes of meetings the same relation value can be noted. The linking of minutes of meetings to relations result into an overview of all available communication about a certain relation. This information is available for the right project participant.

Generally the assignment of extra information has to be possible with all kind of information. The Workflow Management System has to contain a dashboard for storing minutes of meetings, notes et cetera.

Notes

Relation (value)	Note	Action by	Due date
13131 Diesel Generation	Tech. Spec. incorrect	Piet	01-12-2013
1612A001 Pressure vessel	Position incorrect	Jan	15-11-2013

Save

Figure 61 Dashboard to assign notes to relation (values)

Task management dashboard

The WMS have several tasks which will be assigned to project participants. For example the assignment of relations to system parts, the checking of change propagations et cetera. These assigned tasks needs to be settled within a short time to fasten the engineering process. However the engineer is not always logged in the WMS. This situation occurs for example in case of being abroad or in case of subcontracted engineers being part time assigned to a project of DSNS. Therefore it is necessarily to transfer the engineering tasks to the Mail Exchange account of the engineer. Every project participant has an e-mail address, also in case of engineers of subcontractors. The tasks defined in WMS will therefore be sent to the e-mail of the assigned project participant and will have enclosed a reminder.

However an engineer is sometimes not reachable, for example in case of holiday. Therefore unread engineering tasks will transferred to another engineer after 24 hours. The other engineer is the defined deputy. If also the deputy is not able to perform the engineering task, the task will be assigned to the manager of the project participant.

Function: Task assignment (address, due date, description, initiator, procedure)

Receive task containing:

- Adress(users)
- Due date
- Description
- Initiator of task

- When associated to procedure add the initiator of the procedure

Make task

- Description
- Due date

Add task to Task database for later on analysis

If addressed user is out-off-office to end of due time *%% Preventing assignment of tasks to users which are out of office to the end of due time*

Change addressed to user replacement *%% Assignment of task to user replacement, which is a defined user for every user*

Repeat step

Endif

Assign task to user with assigning task to calendar of user

Set end time of task

Send notification to user

Set alarm for at half of due time

If assigned task is not read before half of due time *%% Take action on tasks which are not in progress*

Check if user is logged in

If user is not logged in

Assign task to user replacement

Repeat previous steps

Update dashboard of initiator with task progress

Else give alarm to user

Endif

Notification center

The changes of maturity levels have to be shared with the projects participants. The roles of the participants determine the received notifications. Within the current situation no notification center is available. The notification center therefore has to be part of WMS.

The 3D CAD product model can be viewed with a 3D viewer: the E-browser. At the moment a new 3D viewer is under developing which also includes production information. The new 3D viewer, 'E-share', can also be used to display the maturity level with making use of the defined colors: red, yellow and green. An update into the maturity level can be indicated with a flashing object or notification colors. The implementation of the maturity level indication for revised relation values in the 3D Cad model makes the model suitable for communication of engineering changes to the shipyard. The shipyard themselves can decide how to implement the engineering change and whatever manufacturing information is necessary on the work floor.

To ensure the reading of the notifications, all unread notifications will daily be sent by e-mail to the project participant.

Data structure

The WMS consist of several elements. Firstly the Product Relation Matrix containing the Engineering documents, activities and relations (values). Secondly, the engineering change procedure with the accessory database. Thirdly, a database containing all tasks and notifications. Fourthly, the database containing all data according the project participants. Figure 62 gives an overview of the databases and the relations between them.

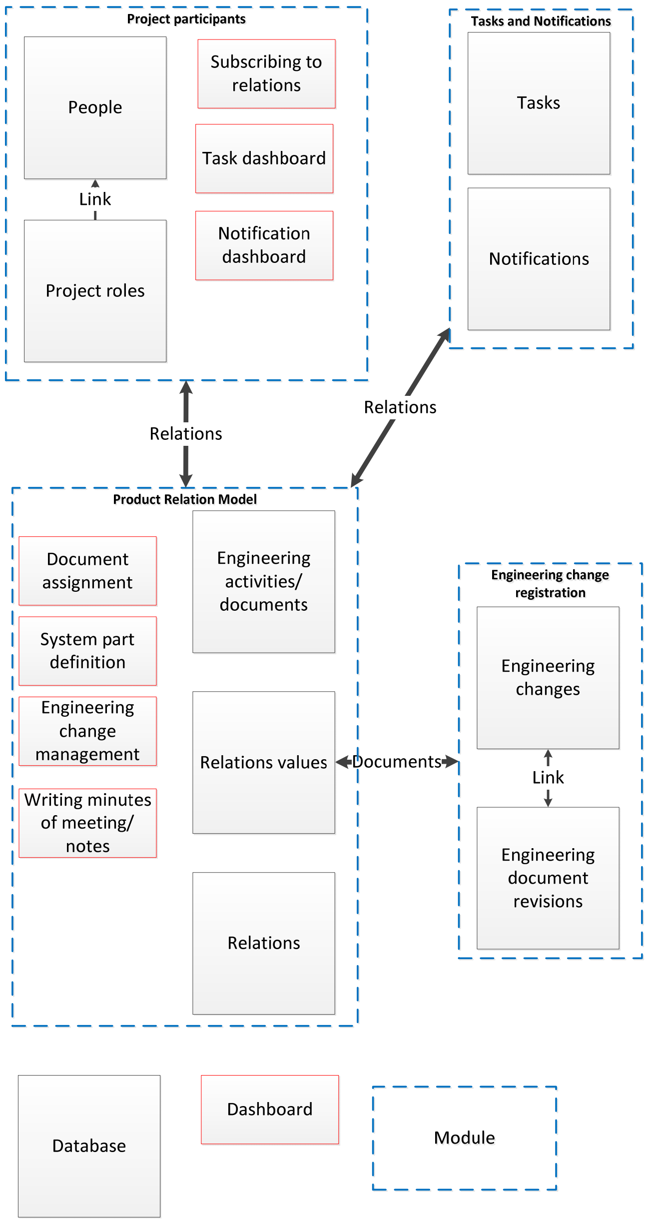


Figure 62 Data structure of the Workflow Management system

6.7 Advantages of the Workflow Management System

The benefits of the product based engineering workflow management are summarized by Schmitt (Schmitt R. , 2005).

- At first the communication times between project participants will become shorter. All communication according engineering information, validation et cetera will be direct digital communicated to the linked project participants.
- The through-put time of engineering changes will be reduced. The engineering change procedure has been able to get the overview of the impact of an engineering change. This throughput time of the first three steps of the engineering change procedure can be performed within one day. There after all consequences of the engineering changes are listed.
- The effort for an engineering change is affected by the impact of the engineering change propagation. The change propagation gives an overview of the necessary project participants for a meeting. This method will prevent of spending time of people which work is not affected by the engineering change. The impact of the engineering change will be direct related to the amount of involved project participants during engineering change implementation.
- The reliability of engineering documents will be improved. The administration of maturity levels of relations will give a direct overview of the reliability of engineering documents. The release of incomplete or unreliable documents will be prevented by displaying the maturity level of the content. Also during engineering change procedures the affected engineering documents will not be released until the engineering change is being implemented.
- Insight in the causes of document revisions with administration of relations. A document revision can be reduced to a specific change of a relation value. The knowledge of engineering changes during the engineering process can be used for improvement of the engineering process. The insight will also result into understanding of decisions according engineering changes by project participants. Some decisions looks wrong and can only being understand with the availability of information of the engineering decision.
- With the quick overview of change propagation the best solution can be chosen with the lowest cost effect on the project process.

7 Financial analysis

The financial result of the implementation of the workflow management will be dependent on two factors. Firstly, the costs of implementation. Secondly, the costs saving by increasing of the productivity. Both factors will be explained within the following paragraphs.

7.1 Cost for implementation

ERP implementation costs

The costs for development and implementation of a Workflow Management System are unknown. Therefore the costs will be reflected against the costs for development and implementation of an Enterprise Resource Planning system.

The costs for implementation consist of several aspects (Chengmeng, 2012):

- Firstly, the development of the Workflow Management System. The cost for development will be in a range of about € 1,000 until 4,000 per user (Kosten van ERP-implementatie) (Inspired, 2013) (Kaupp, 2012). The costs will be highly dependent on the complexity of the software. Beside the complexity also the integration with existing software will increase the development costs. This will be the case with the integration of the WMS with Teamcenter and VDDS. The implementation costs for WMS will be lower than for ERP software, which will be more complex with the including of financial aspects.
- Secondly the costs for implementation consisting training and education, adjusting work procedures and data migration. This is not only restricted to Damen employees, but also subcontractors need this training. The implementation costs will be estimated on 1 to 2.5 times the cost for development (Kosten van ERP-implementatie) (Inspired, 2013) (Kaupp, 2012). Therefore the implementation cost will be in a range of about € 1,000 until 6,000 per user. Data migration is not required with the implementation of WMS. Existing data will not be transferred and the new WMS can be used for new projects.
- Thirdly, operational costs as maintenance of servers, system manager. The operational costs are low in relation to the other costs.

The ERP implementation and development costs will be in the range of € 2,000 until 10,000 per user. The next paragraphs shows the options for cost saving.

Cost saving by implementation

Above paragraph shows the estimation for the development and implementation of ERP software. The cost for WMS can be lower with selection of one of the following options:

The first approach is the adjustment and extending of the recently developed VDDS tool. The VDDS tool is specially developed for the engineering process of DSNS and can be the starting point of the development of the Workflow Management System. The advantages for this approach are the availability of interfaces with the Product Data Management (Teamcenter). This will decrease the initial development cost. However the VDDS tool is a small tool developed for only managing the receiving process of engineering information from suppliers, which is only one step of the engineering workflow. It is unknown if these tool is capable to manage the higher account of information. More over WMS needs a further integration with the current Product Data Management (Teamcenter) and the 3D CAD software (Cadmatic). The check of new relations in documents, the assignment of maturity levels on relation values and the integration of the maturity level control with the validation process of Teamcenter requires a further integration.

The second approach is the completely integration of the WMS in PDM. This requires the implementation of all functions of WMS in Teamcenter or integrates the functions in the new upcoming ERP package: 'IFS'. IFS is currently implemented in the project process of Damen Gorinchem and in future it will be implemented in all Damen companies. IFS includes Product Data Management and will replace Teamcenter. The implementation of IFS gives the opportunity for a proper implementation of the functions of WMS. This gives the following advantages:

- Lower development cost with the availability of a platform which contains the product structure, authorization and documentation.
- Integration of WMS and PDM which results in a higher efficiency.
- Lower implementation costs with the possibility to combine the training for IFS and the developed WMS.
- Simultaneously introduction of new ERP, PDM and WMS in new projects. This will have lower cost instead of separate introductions of the software.

Conclusion

The costs for implementation and development for ERP software are in a range of € 2,000 until 10,000. The implementation of the new ERP software IFS, which includes Product Data Management, will result into lower costs for development and implementation of WMS. The costs for implementation development of the WMS will therefore be estimated on € 2,000 until 4,000 per user. The total costs for the engineering department of DSNS with about 150 engineers will be about € 300,000 until 600,000.

7.2 Cost saving

An increase of the productivity will result into a decrease of the labor costs of the engineering process. The WMS will contribute to the increase of the productivity. This increase can be calculated based on increasing efficiency or effectiveness of the engineering process.

Efficiency increase

Firstly, the increase of efficiency of the engineering process. Rouibah gives an overview of the time spend by engineers on the different tasks (Figure 63). The 24 percent of 'Waiting for' and the 31 percent of 'Communication' gives an indication of the possibility for increasing efficiency of the process.

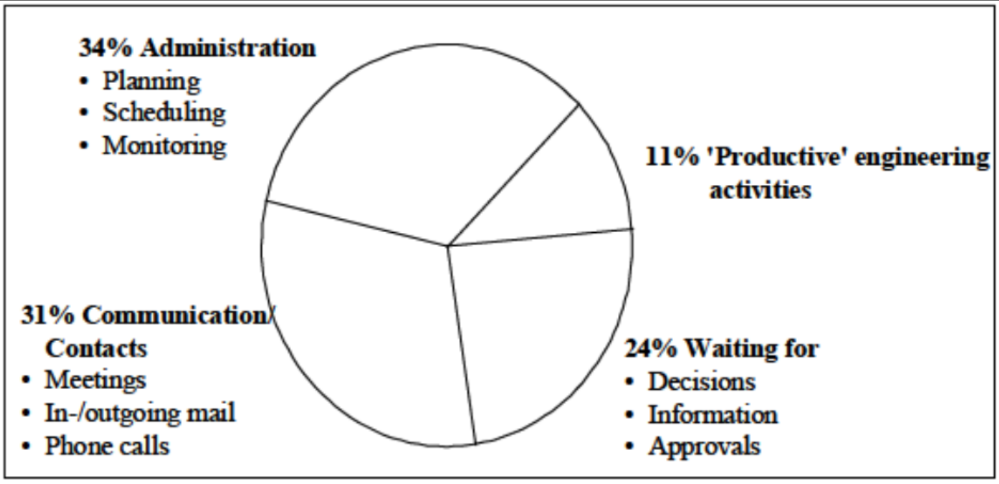


Figure 63 Spend time overview on several tasks (Rouibah, Managing Concurrent Engineering across Company Borders: A Case Study, 2002)

The WMS contributes to a higher efficiency of the engineering process by:

- Giving the individual engineer overview of the available and missing information. This makes it possible to take into account current available information.
- Giving the possibility to watch the progress and to take action if information is delayed while an overview of engineering information is available.
- Making links between all sort of engineering information by WMS as: minutes of meetings, notes, engineering documents et cetera. The direct link will decrease the spend hours on searching for information by the individual engineer. All released engineering is directly addressed to all interested project participants. This will also prevent from doing work which is already performed by other project participants.

- Increasing the response of the individual engineer to the actual situation by the addressing of engineering information to the interested project participants. The throughput time of release of engineering information and receive them by an engineer will be negligible.

An engineer will have about 46 working weeks, with each 40 working hours. An increase in efficiency will decrease the spend engineering hours on an activity. The following calculation can be used for the effect of an efficiency increase of one engineer:

$Hours\ Saved \coloneqq Percentage * 46 * 40 \coloneqq € \, 1380$

This results in:

Percentage	Hours saved	Costs saved yearly
1%	18.4	€ 1380
2%	36.8	€ 2760
3%	55.2	€ 4140
4%	73.6	€ 5520
5%	92	€ 6900

Effectiveness increase by reduction of rework

According Reefman an average engineer is spending 40 to 60% of the engineering hours on rework related to revision management (Reefman & Nederveen, 200x). The WMS can decrease the spend engineer hours on rework. This is the result of the engineering change procedure which increases the efficiency of this procedure as follows:

- The group of project participants which will be involved in the problem-solving step of the engineering change procedure is restricted to people who are responsible for the affected relation values.
- The engineering change procedure gives the possibility to notify other departments for upcoming changes, which can anticipate with completely stop the affected activities or adjust the execution of the affected activities.
- The engineering change procedure can contribute to the decrease of spending engineering hours related to the release of revised manufacturing information.
- The implementation of maturity level will give attention to the reliability of engineering information. This will increase the reliability of engineering information and will decrease rework.

The saving costs will be related to the decreasing hours spend on the settlement of 'Non Conformity Notes'. This category is used for releasing engineering changes to production. The data is extracted of a project for the new build of a frigate. The saving costs in production will be estimated at four times the saving costs in engineering. This is based on the estimating of employees of DSNS (see chapter three). The following data and calculations are done:

Engineering hours total	130,000
Notes of Nonconformity	12,000
Direct Engineering hours	65,000

Saving	Hours	Engineering cost	Production cost	Total cost
2%	240	€ -16,800	€ -67,200	€ -84,000
5%	600	€ -42,000	€ -168,000	€ -210,000
10%	1200	€ -84,000	€ -336,000	€ -420,000

Calculations

$Hours := Savingpercentage * Hours\ Non\ Conformity\ Notes: = 2\% * 1200 = 240$

$Engineering\ cost := Hours * -hourcost := 240 * -€70, -= -€\ 16{,}800, -$

$Production\ cost := Engineering\ cost * 4 := -€16.800 * 4 = -€67{,}200, -$

$Total\ saving := Engineering\ cost + Production\ cost := \ -€\ 84{,}000, -$

7.3 Conclusion

The implementation and development of the WMS is estimated on € 300,000 to 600,000, or € 2,000 to € 4,000 per user. This will only be achieved with the combination of the development and implementation of the new ERP software: 'IFS'.

The cost saving of the WMS can be calculated by the efficiency increase of 1%, which results in a saving of €1,380. This will result into a payback period of about 2 to 3 years. In case of cost saving as consequence of an increasing effectiveness will result into the following cost saving for one new build project of a frigates:

- 2% time saving in Non Conformity Notes: 84,000 Euro
- 5% time saving in Non Conformity Notes: 210,000 Euro
- 10% time saving in Non Conformity Notes: 420,000 Euro

Multiple projects are necessary for pay back the investment. There can be concluded that the return of the investment is only possible with the implementation and development of WMS in combination with the implementation and development of the new ERP system: 'IFS'. Without this combination the development and implementation costs will be too high.

8 Discussions and conclusions

8.1 Conclusion

The starting question of this thesis was:

"How is the current Workflow Management System and does the current system complies with current project requirements: delivering on time, high quality, and lowest cost?"

The answer for the first part of the research question is defined in the analysis of the engineering process of DSNS, as described in chapter three. The analysis resulted into the design of a Workflow Management System:

"Develop a Workflow Management System that is able to manage the planned and ad-hoc information flows, supported by a Workflow Management System, which contributes to:

- Lower costs
- Increased of efficiency of engineering
- Identical or shorter throughput time of engineering"

The answer is the design of a Workflow Management System which is able to:

- ➢ Address engineering information to project participants in such a way that: firstly, the project participant receives the right engineering information and secondly, shortens the lead time between releasing and receiving of information.
- ➢ Controls of the ad-hoc information flows to decrease the impact of them by analyzing the ad-hoc information flows and consider a cost effective and efficient solution which has the lowest impact on the total cost and delivering time of the project.
- ➢ The applied concurrent engineering approach requires the assignment of maturity levels to engineering information. The maturity level has to be assigned in more detail to parts of engineering documents.

The Workflow Management System is defined in chapter five and six. The Workflow Management System contributes to:

- ➢ A higher efficiency of the engineering process. The product, defined in the Product Relation Matrix, is able to address the engineering information to the engineer. Furthermore, the engineer is supported with a dashboard which displays the available engineering information and tasks which have to be performed. The Workflow Management System supports the engineering change procedure.

- The costs for the engineering process will decrease after earn back of the investment for the design and implementation of the Workflow Management System. The return on investment will be about two to three years. This can only be achieved with combined implementation of WMS with the new ERP software 'IFS'.
- The throughput time of engineer can decrease. Firstly, the quick addressing of engineering information decrease the throughput time of engineering. Secondly, the Workflow Management System can result in less rework. Thirdly, the handover of engineering changes to the engineering process can go faster. The implementation of maturity levels in the 3D CAD model will make it possible to use the 3D CAD model for communication of engineering information.

Within the next two paragraphs the benefits of Workflow Management System will be explained and abbreviations will be included.

8.2 Benefits of Workflow Management System

Benefits

- Short communication lines between people, whereby all people receive what they need. The project participant can focus on his task. Direct communication between people is possible, but will registered in WMS.
- The impact of the engineering change will be direct related to the amount of involved project participants during engineering change implementation.
- Insight in the causes of document revisions with administration of relations. A document revision can be reduced to a specific change of a relation value. The knowledge of engineering changes during the engineering process can be used for improvement of the engineering process.
- The reliability of engineering documents will be improved. The administration of maturity levels of relations will give a direct overview of the reliability of engineering documents.

Issues for implementation

- The approved documents will be representing a set of relation values. The set of relation values doesn't have necessarily the same maturity level. The maturity level isn't showed on the printer engineering documents. A possible solution is the using of colors on the 2D drawings, which will involve extra printing costs or the use of bold or underlined system part numbers on the drawing to display the differences in maturity level on the printed 2D drawings.

- The validation process of relation values will not be part of the used engineering software. The success of the Workflow Management System is based on the readiness of the project participants. The readiness will enlarge when there is understanding of the benefits of the workflow management. The direct communication and traceability of engineering information will be sufficient to convince a part of the project participants. The other part has to be stimulated and will see the benefits in the course of the project.
- The implementation of WMS will be giving the best result in a transparency culture. The implementation of the new Workflow Management System must go in hand with the changeover to a transparent business culture. The traceability of engineering documents as well communication notes will take care for reservations of people against the new information management system.

8.3 Abbreviations

- The Workflow Management System has been explained and worked out in an implementation proposal. However this management system can be enlarged to other processes. The communication and relationships between departments will be displayed. The workflow of the relations can be enlarged with the including of other non-engineering activities. The Product Relation Matrix can display the whole process from contract specification until the end of warranty and will so become one source of truth. It's abbreviated to start with the enlarging of the implementation of the production status. This will support the engineering change procedure with accurate information according the influence on the production process.
- The links of relations to project participants can also be used for the review of relation values by specialists and other project participants. The maturity level 'final' can be used to give other project participants and specialists the possibility to comment on the relation value, without using a formal procedure. The review of the relation value can decrease the amount of document revisions (Reefman & Nederveen, 200x).

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Design of a Workflow Management System for the Engineering Process of Damen Schelde Naval Shipbuilding

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***Abstract*—This paper defines a Workflow Management System (WMS) for an engineer-to-order process. The engineering process is characterized as a iterated process whereby functions are performed in parallel. Moreover the engineering information will change as consequence of new requirements, changing specifications of delivered components. The main purpose is to become to a definition of a Workflow Management System which is be able to increase the efficiency, lowering costs of the engineering process. The research is initiated in order to decrease the costs of engineering of naval vessel by Damen Schelde Naval Shipbuilding.**

***Index Terms*—Workflow Management System, Engineer-to-order, Naval, Concurrent Engineering, Validation**

I. Introduction

Damen Schelde Naval Shipbuilding (DSNS) is delivering naval vessels to customers all over the world. DSNS is well-known for its high quality and delivering on time. The market of DSNS is shifting as result of the budget cuts of the Royal Netherlands Navy and the growing defense budget of the Asian countries. The new market demands competitive prices, local shipbuilding and transfer of technology.
The focus within the engineering process has always been on product quality. The focus has resulted in the high quality of the naval vessels, which is confirmed by the customers. The efficiency of the engineering process is attracting more attention, as consequence of the decrease of engineering budget.

The delivering of one-offs customized naval vessels requires an engineer-to-order process. The growth process of engineering can be characterized by highly interrelated engineering activities, planned and ad-hoc information flows. The engineering process has to increase the productivity to lower the cost of engineering.

II. Method

This paper gives a summarization of the performed analysis of the engineering process of DSNS. The analysis results in a problem definition which leads to the requirements of a Workflow Management System, implemented in the engineering process of DSNS. These requirements will result in a framework for WMS containing all required functions. The framework consist of the product structure. The implementation proposal will be shortly discussed.

III. Analysis of the Engineering Process

The analysis is performed according the Delft Systems Approach [1]. Firstly, the positioning of the engineering process as part of the total project process is defined. With the use of the Process Performance model the aspect flows of interest are modeled (Fig. 1).

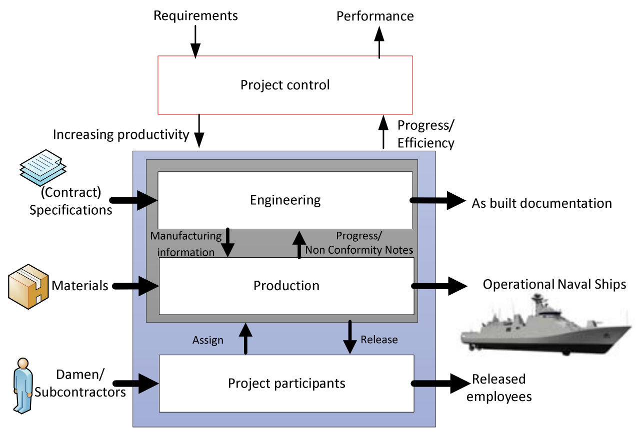

Fig. 1 ProPer model of a project process

The standards for the project process are an increasing productivity, lower costs and remaining delivery-on-time. These standards are applied to the engineering process, which can be typified as a growth process.
During the project client requirements may change and the delivered equipment specifications will change also. The technical development of equipment doesn't stop and some equipment will have their own engineering process in parallel with the engineering process of DSNS. At the start of the production less then 90% of the main equipment is registered and at the end of Basic Engineering 90% is achieved.

The analysis has resulted into three elements which need to be implemented into the engineering process of DSNS. Firstly, a Workflow Management System which is able to: address the engineering information to project participants, assignment of maturity levels and the management of ad-hoc information flows to result in an efficient and lowest cost solution.
Secondly the implementation of manufacturing engineering

which increases the effectiveness and efficiency of the release process of manufacturing information. Thirdly, the implementation of an evaluation process, which is able to suggest project process improvements.

IV. PROBLEM DEFINITION

The solution provided in this research contains the required Workflow Management System. Therefore manufacturing engineering and the evaluation of project results will not be taken into account. To ensure a proper implementation of these elements in future, these elements will be part of the prerequisites of the implemented solutions. The problem definition in this research becomes:

"Develop a Workflow Management System that is able to manage the planned and ad-hoc information flows and contributes to: lower costs, increased productivity of engineering and identical or shorter throughput time of engineering"

A. Addressing of engineering information

To achieve these requirements three functions are defined which have to be part of WMS. Firstly, the planned and ad-hoc workflows need to be addressed to the right project participants, dependent on the role of the individual project participant. The engineer performs engineering tasks according to his role in the engineering project. The role of the engineer determines the required engineering information. Addressing of engineering information to engineers has to be extended with the following functions.

1) Right engineer
Sending all relevant information to the right engineer. As earlier mentioned this means not only engineering drawings, but also engineering decisions, notes of other engineers et cetera.
2) Notification
Notification of the engineering about the received information. Ad-hoc engineering information is not expected by the individual engineer and needs to be pushed to the engineer.

B. Assignment of maturity level

Secondly, the engineering information has to be assigned with a maturity level. These maturity levels represent the reliability of information and give guidance to the users of the engineering information according usability, probability of change et cetera. The elements which will be used for assignment of the maturity level will be a consideration between workload of administration and the required detail of maturity of engineering information. The element for administration of the maturity level may differ according the engineering information.

C. Ad-hoc information management

Thirdly, the ad-hoc engineering information has to be analyzed to determine the change propagation and influence on the engineering and production process. The workflow management will support this analysis. The ad-hoc workflows are defined during the project, contrary to the planned workflows. The workflow management has to be able to define in an efficient way the new originate workflows as consequence of the release of ad-hoc engineering information.

V. WORKFLOW MANAGEMENT SYSTEM

A. Product Centered

The classical workflow management is well suited for handling of planned workflows. The activities and exchange of engineering information is defined before the start of the project. The classical workflow management is insufficient in the management of the ad-hoc information, resulting in ad-hoc workflows. It is not able to properly address the ad-hoc information by definition of the ad-hoc workflow.

A solution could be the use of the product-structure as basis for the workflow management [2]. Joeris defines the product-centered aspect as one of the requirements for workflow management within a product design environment [3]. Engineering document changes will propagate through product relations to other

System part	Description	13131 DG system	1612 Starting Air	1300 Eletrical system	1434 Crabbing Cranes
JS13131 - XA0001AA	V12 DIESEL GENERATOR SET 1 SB FWD	F	I		I
JS13131 - XE0009AA	24VDC SUPPLY CABINET DG SET 1	F		I	I
JS13131 - XE0016AA	ENGINE CONTROL CABINET V12 DG SET 1	F		I	I
JS13131 - XE0020AA	JUNCTIONBOX ON ENG V12	F		I	I
JS13131 - XE0030AA	RESISTOR JUNCTION BOX	F		I	
JS1612 - XA0001AA	STARTING AIR COMPRESSOR D G RM 1		F		
JS1434 - XA0002AA	DG1 GANTRY CRANE				F

Fig. 2 Product Relation Matrix

documents and accessory engineering activities. These product relations have to be known for proper control of the ad-hoc workflows and are defined in the product structure.

A common method of product dependency definition is the Design Structure Matrix (DSM). In general, the component based DSM is applied, which shows the dependence between components in a n x n matrix. the component based DSM does not clearly visualize the presence of multiple dependencies between components. These multiple dependencies are very important within the estimation of engineering change propagation [4].
Roubaih and Caskey developed the parameter based engineering (change) management, part of the SIMNET project [5][6]. This method is using a parameter-based DSM. A selection of parameters defines the direct and indirect dependencies between components. The dependences are displayed with use of a parameter network. Both methods require extra work with definition of all dependencies between components or the transfer and definition of all parameters into one database.

For minimization of the extra work and costs the Workflow Management System has to use the existing product structure with the available dependencies. The product structure is defined by the Schelde System Work Breakdown Structure (SSWBS). In this structure every system part (component) is member of one system of the SSWBS. The relation is based on the function of the system part. The system parts of the hydraulic system are all system parts which are fulfilling the function 'providing hydraulic pressure for other components'. The relation of the system part is expressed in the system part coding, which includes a system number. The DSM is becoming a relation-based design structure matrix.

B. Product Relation Matrix

The Product Relation Matrix (PRM) defines the relation between a component and one or more systems of the SSWBS. A dependency between components is defined by the relation of both components to an identical system: Component to system, system to component.

The dependencies are defined with use of the existing product structure and minimize the extra work to define all dependencies between components. The dependency of a component to a system will be named: relation. The definition of a relation inside an engineering document will be named: relation value. The Product Relation Matrix is the collection of all relations. The objects of the matrix are the components of the product. The aspects of the matrix are the systems of the product, retrieved from the SSWBS.
The relationship between a component and a system is defined with a relation. The relation can be a functional relation: "The component is a functional part of the system." The functional relations are already registered in the current Product Data Management system. The second group are the interface relations: "The component is for operation dependent on the system and has therefore an interface to the system."

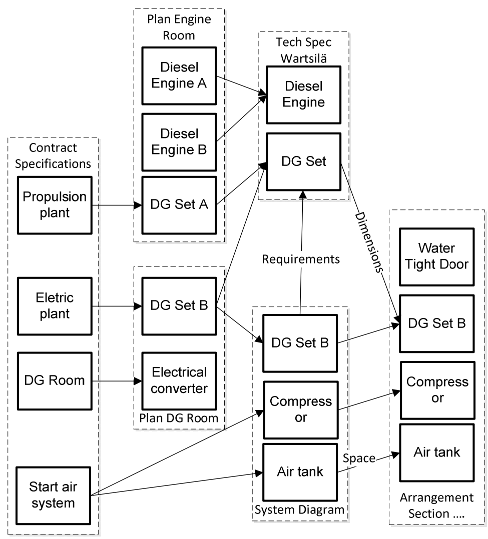

Fig. 3 Engineering workflow

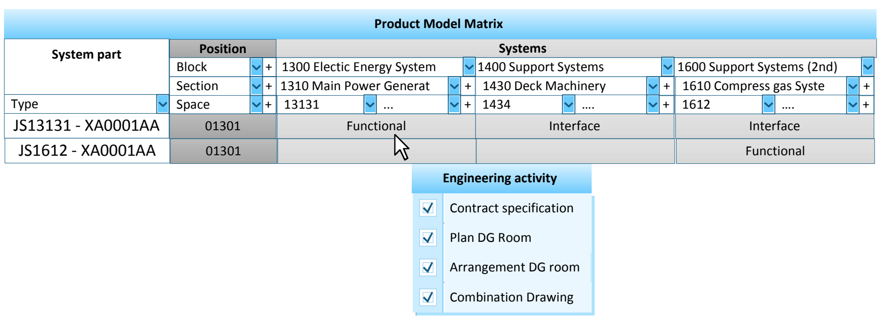

Fig. 4 Registrations of system parts and relations in the Product Model Matrix

C. Engineering document definition

With the definition of the PRM the definition of an engineering workflow becomes: "The sequential engineering transformation functions applied to one relation." The engineering transformation functions are the engineering activities, or otherwise called the engineering tasks. The engineering workflow defines the dependency between engineering information and the accessory activities.

The definition of an engineering document becomes: "An engineering document captures the results (relation value) of one engineering transformation function applied to a collection of relations." The collection is defined by: Firstly selection of one or more systems of the SWBS. Secondly, narrowing the selection to a type of system parts or/and a special part of the naval vessel.

The content of an engineering document could not always be defined by a collection of relations. This is part of the system engineering approach which defines the product from mission to the smallest element: the system part. The engineering documents which are describing the functions and systems of the product don't contain a description of the individual system part. Even the system parts are not defined at the moment of this document release. These documents can only be defined by an area of the PRM and further detail is not available. The product definition level defines the relationship between an engineering document and the relations. The product definition level consist of three SWBS levels, system part, relation and item level.

D. Engineering document validation

The sharing of preliminary documents requires an indication of the maturity level of the content of the document. The maturity level of preliminary documents cannot be captured within a general validation status of the complete document. Therefore the maturity level will be assigned to every relation of an engineering document. This will result in a maturity level for every iteration step of a relation value. When a relation workflow consists of five engineering activities, the relation value will be assigned with five maturity levels.
The maturity levels are:

1) Unworked: The relation value is unknown.
2) Preliminary: The relation value is captured with a preliminary value.
3) Final: The relation value is final but not validated.
4) In check: The relation value is in process for validation and will be checked by the Team Leader.
5) Approved: The relation value is approved by the Chief engineer.

E. Engineering change procedure

The analysis of the engineering change comprises four steps. Firstly, the engineering change will be linked to a relation. The relation will become 'In change' and becomes the origin of the engineering change process. Secondly, determination of engineering propagation to the other relations of the system part (horizontal change propagation). Thirdly, determination of vertical engineering change propagation to other aspect systems of the affected relations. Finally, if aspect systems are affected the affected relations of these aspect systems has to be listed. These relations become the starting of a new iteration step following the four steps. The procedure will stop if no more new propagations have been found. Finally, the known change propagation can be discussed and a solution can be defined.
A very important part of the workflow management is the administration of the engineering process. During the engineering process decisions are made and engineering changes are applied to the design. The engineering process can become a source of information for future processes. A change in engineering can become a disturbance for the process of engineering and production. Disturbance analysis will be based on the engineering changes and has to be able to track back to the origin of the engineering changes.

F. Notification and Task assignement

Every engineering activity is assigned to a group of engineers, all having their individual role to the engineering activity. Engineering information will achieve engineers with the following sequential steps:

1) Engineering information
2) Relation value
3) Relation
4) Engineering activity/document
5) Linked engineer

In this way the engineer will receive the right information and will be prevented from overload of engineering information. Individual engineers have to be able to enlarge the receiving of information by assignment to extra engineering activities, collections or individual relations.
The engineers will be supported with an information portal which provides access to the received engineering information. New information will be added to the portal during the project, maturity levels changes and even the Product Relation Matrix can extend during the process with the adding of new systems or system parts. The engineering has to be notified for new or changed information and has to be supplied with an engineering information overview.

G. Links to other information

The engineering information is not limited to the engineering drawings and other official design documents. There is much more information available which will describe, define or have another contribution to the engineering process. Notes of engineers, progress reports, minutes of meeting, et cetera. For example the minutes of meeting which will give guidance to the engineering process and includes engineering decisions, explanation of client et cetera. All these information has to be handover to the engineer for an efficient and effectiveness process. Addressing of this information can be performed with use of the PRM. The information is assigned to a collection of relations and in this way the project participants are addressed with all required information.

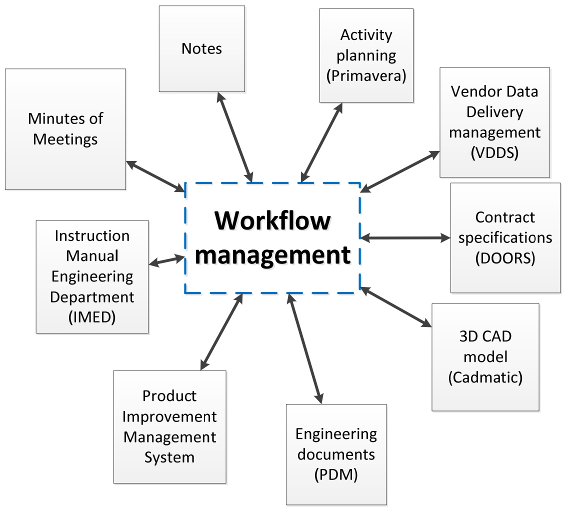

Fig. 5 Extending the linked information of the Workflow Management System

VI. Financial Results

The implementation and development of the WMS is estimated on € 300,000 to 600,000, or € 2,000 to 4,000 per user. This will only be achieved with the combination of the development and implementation of the new ERP software: 'IFS'.

The cost saving of the WMS can be calculated by the efficiency increase of 1%, which results in a saving of € 1,380 Euro. This will result into a payback period of about 2 to 3 years.

In case of cost saving as consequence of an increasing effectiveness will result into the following cost saving for one new build project of a frigates:

1) 2% time saving in Non Conformity Notes: € 84,000
2) 5% time saving in Non Conformity Notes: € 210,000
3) 10% time saving in Non Conformity Notes: € 420,000

Multiple projects are necessary for pay back the investment. There can be concluded that the return of the investment is only possible with the implementation and development of WMS in combination with the implementation and development of the new ERP system: 'IFS'. Without this combination the development and implementation costs will to high.

VII. Conclusions

The Workflow Management System contributes to:

1) A higher efficiency of the engineering process. The product, defined in the Product Relation Matrix, is able to address the engineering information to the engineer. Furthermore, the engineer is supported with a dashboard which displays the available engineering information and tasks which have to be performed. The Workflow Management System supports the engineering change procedure.
2) The costs for the engineering process will decrease after earn back of the investment for the design and implementation of the Workflow Management System. The return on investment will be about two to three years. This can only be achieved with combined implementation of WMS with the new ERP software 'IFS'.
3) The throughput time of engineer can decrease. Firstly, the quick addressing of engineering information decrease the throughput time of engineering. Secondly, the Workflow Management System can result in less rework. Thirdly, the handover of engineering changes to the engineering process can go faster. The implementation of maturity levels in the 3D CAD model will make it possible to use the 3D CAD model for communication of engineering information.

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[2] Roubaih, K., & Caskey, K. (2003). A workflow system for the management of inter-company collaborative engineering processes. *Journal of Engineering Design*, 273-293.
[3] Joeris, G. (1997). Cooperative and Integrated Workflow and Document Management for Engineering Applications. 68-73.
[4] Habhouba, D., Cherkaoui, S., & Desrochers, A. (2011, May). Decision-Making Assistance in Engineering-Change Management Process. *TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART C: APPLICATIONS AND REVIEWS*, pp. 344-349.
[5] Rouibah, K., & Caskey, K. (2003). Change management in concurrent engineering from a parameter perspective. *Computers industry*, 15-34.
[6] Yang, J., Goltz, M., & Han, S. (2004). *Parameter-Based Engineering Changes for a Distributed Engineering Environment.* Pennsylvania States: SAGE Publications.

Appendix B Products and engineering

Product description of the Joint Support Ship: Karel Doornman

Figure 64 Joint Support Ship in the middle **(Ministry of Defence)**

The Joint Logistic Support Ship (JSS) is being built to ensure that the Netherlands armed forces will remain able to conduct operations outside the national boundaries in the future. In this context, the vessel is being built for 3 main tasks:

- Resupply at sea to support maritime units.
- Strategic sea transport, including debarkation and embarkation of staff and materiel if there are limited or no port facilities available.
- Logistic support at sea (sea basing), in which the vessel serves as the base at sea from which land operations are conducted and supported.

It is important that these tasks can be carried out in all parts of the spectrum of force, for instance during armed conflicts, warfare and civil support operations.

Specifications

Length 204.7 m
Width 30.40 m
Height 53 m (including mast)
Weight of empty vessel 17,200 tonnes
Weight of load max 10,600 tonnes
Draught max 8 meters
Displacement max 27,800 tonnes
Propulsion diesel-electric
Maneuvering 2 propellers and rudders, 2 bow propellers, 1 stern thruster
Power 26 MW
Armament Close-in weapon system (Goalkeeper) AT/FP automatic gun system 30mm, automatic .50 machine gun system, machine gun positions 7.62mm
Accommodation 300 (crew and temporary crew)
Special features: The JSS will be equipped with a crane and lift to hoist heavy materiel. The vessel can transport about 5,000 tonnes of heavy rolling (armoured) materiel. The vessel will have a hospital with 2 operating theatres. The JSS will also have landing pads for helicopters, such as Chinooks and Cougars.

Platform
Damen Schelde Naval Shipbuilding (DSNS) is the main supplier for the JSS platform. The hull construction work and a large part of the vessel's completion will take place at Damen Shipyard Galati in Romania. The commissioning and outfitting will take place at DSNS's facilities in Vlissingen.

Mast with integrated sensor and communication suite
Thales Nederland is the supplier of the sensor and communication mast, the so-called Integrated Sensor and Communication Suite (GSCS). This mast is virtually identical to the ones of the navy's patrol vessels. The Defence Naval Sustainment and Maintenance Organisation, in cooperation with Thales, is building the integrated mast.

(Ministry of Defence)

Shipbuilding facts

Systems about 250 (sub)systems
Components 86.000 components
Effective Date of Contract 12-2009
Keel laid down 06-2011
Commissioning 2015

Product standardization

SIGMA denotes: Ship Integrated Geometrical Modularity Approach (Figure 8). The concept is based on fixed section length. The client can compose a vessel with standard blocks. The advantages for the client are (SIGMA Series):

- Flexibility in optimum arrangement
- Easy implementation of modifications or upgrades in future

- Lower price through the use of standard equipment and repetitive design
- Wide selection of hull dimensions and different combat suites
- Short lead time through standardization and modular set-up
- In practice, the mentioned advantages are more challenging than anticipated. The concept of SIGMA was first materialized with the first SIGMA design for Indonesia. The order contained four SIGMA Corvettes 9113, which are 91 meters long and 13 meters wide. Directly after Indonesia an order for Morocco followed with two 9813 and one 10513.

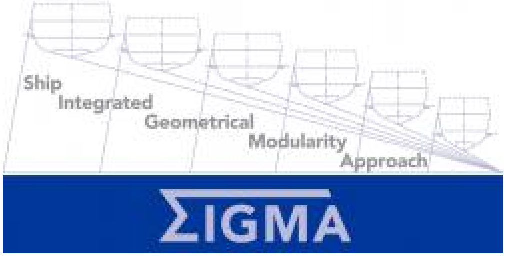


Figure 19 Sigma symbol

After seven SIGMA vessels built and one SIGMA 10514 on order for Indonesia, a solid base for engineering, assembly and budgeting is established. To shorten the time to give a budget price the project 'Standaard Ladenkast' (STALK) was initiated which is aimed at developing three SIGMA vessels with different length. STALK will give common solutions for client requirements.
STALK is part of a larger improvement project ('Verbetertraject'). The common solutions of STALK are used to make a selection of standard parts which can be used in all products. The standardization project is directed by the Purchasing Department and has the goal to shorten the purchase loop and make technical information readily available.

Modular shipbuilding

The production and completion of vessels took place in Vlissingen originally. The last time several vessels (JSS, PS3, PS4) where build in Galati, where after the completion is done in Vlissingen. At the end the Harbor Acceptance Test (HAT) and Sea Acceptance Test (SAT) is done. The crew gets training organized through Integrated Logistic Support (ILS). Above process takes place in two countries. All functions have one location, so production in Romania, completion in Vlissingen et cetera.
With the new situation of modular building functions will be done parallel on different countries. So for example production takes place in Vlissingen, Romania and Indonesia (Figure 10). This building process has the following consequences:

- Similar functions parallel on different locations (Production, Production Support, Setting to work)
- Use of local suppliers
- Supply chain with three destinations, which is possible with the following methods:
    - Using Vlissingen as cross docking location with temporary storage

- supplier supplies directly to all shipyards

- combination of the above
- setting to work before completion of the whole vessel
- Transportation of vessel modules

Appendix C Information structure

Schelde System Work Breakdown Structure

0000 - GUIDANCE AND ADMINISTRATION
- 000X - GUIDANCE AND ADMINISTRATION
- 060X - SUBSYSTEM CHARACTERISTICS
- 0610 - HULL CHARACTERISTICS
  - incl. General description of the construction
- 0620 - PROPULSION SYSTEM CHARACTERISTICS
  - incl. General description of the propulsion
- 0630 - ELECTRICAL PLANT CHARACTERISTICS
  - incl. General description of the electric system
- 0640 - COMBAT AND SURVEILLANCE SYSTEM CHARACTERISTICS
  - incl. General description of the combat system, incl weapon systems
- 0650 - AUXILIARY SYSTEMS CHARACTERISTICS
  - incl. General description of de auxiliary systems
- 0660 - OUTFITTING CHARACTERISTICS
  - incl. General description of de accommodation, incl hotel systems
- 0670 - ARMAMENT CHARACTERISTICS
  - incl. General description of de weapon systemen

1000 - HULL STRUCTURE
2000 - PROPULSION PLANT
3000 - ELECTRIC PLANT
4000 - COMMAND AND SURVEILLANCE
5000 - AUXILIARY SYSTEMS
6000 - OUTFIT AND FURNISHING
7000 - ARMAMENT
8000 - INTEGRATION ENGINEERING GENERAL
9000 - SHIP ASSEMBLY AND SUPPORT SERVICES
F00 - LOADS
P000 - COSTS SURCHARGES
S000 - SALES ITEMS
Z000 - TEMPORARY LOCATION FOR LOGISTIC COST

Identification and documentation[2]

System

Used by: Engineering, Production, IBS

Identification: Product Breakdown Structure (PBS)

Description: A composition of sub-systems, assemblies, skills and methods, capable to execute and/or support an operational or non-operational function.

[2] Configuration Management Plan

A complete system comprises related skills, Items, materials, services and personnel, necessary to function on a level, considered as an independent Item, in its proposed operational or non-operational and/or supporting environment. In this document a system is specified excluding personnel and services.[3]

Documentation: Teamcenter, Cadmatic, Microstation

System Part

Used by: Engineering, Production, IBS, Expediting

Identification: Product Breakdown Structure (PBS)

Description: A System Part is a technical product which, in a physical way, fulfils a standalone role and on a higher level in the hierarchic classification fulfils or can fulfil a specific, identifiable function.

Documentation: Teamcenter, Cadmatic, Microstation

Item

Used by: Procurement, Expediting

Identification: Product Breakdown Structure (PBS)

Description: All vessel's hardware, requested, ordered and installed.

Documentation: Teamcenter, Baan

Product Breakdown Structure

The current configuration management is document based. At the beginning of a project the standard for a project is laid down into the contract specifications. The contract specifications are made by using the DOORS software.

The contract specification is structured with using the Schelde System Work Breakdown Structure (SSWBS), which is explained in 0. The SSWBS is a Product Breakdown Structure (PBS) which exist of a system and spatial structure.

[3] Configuration Management Plan page 13/24

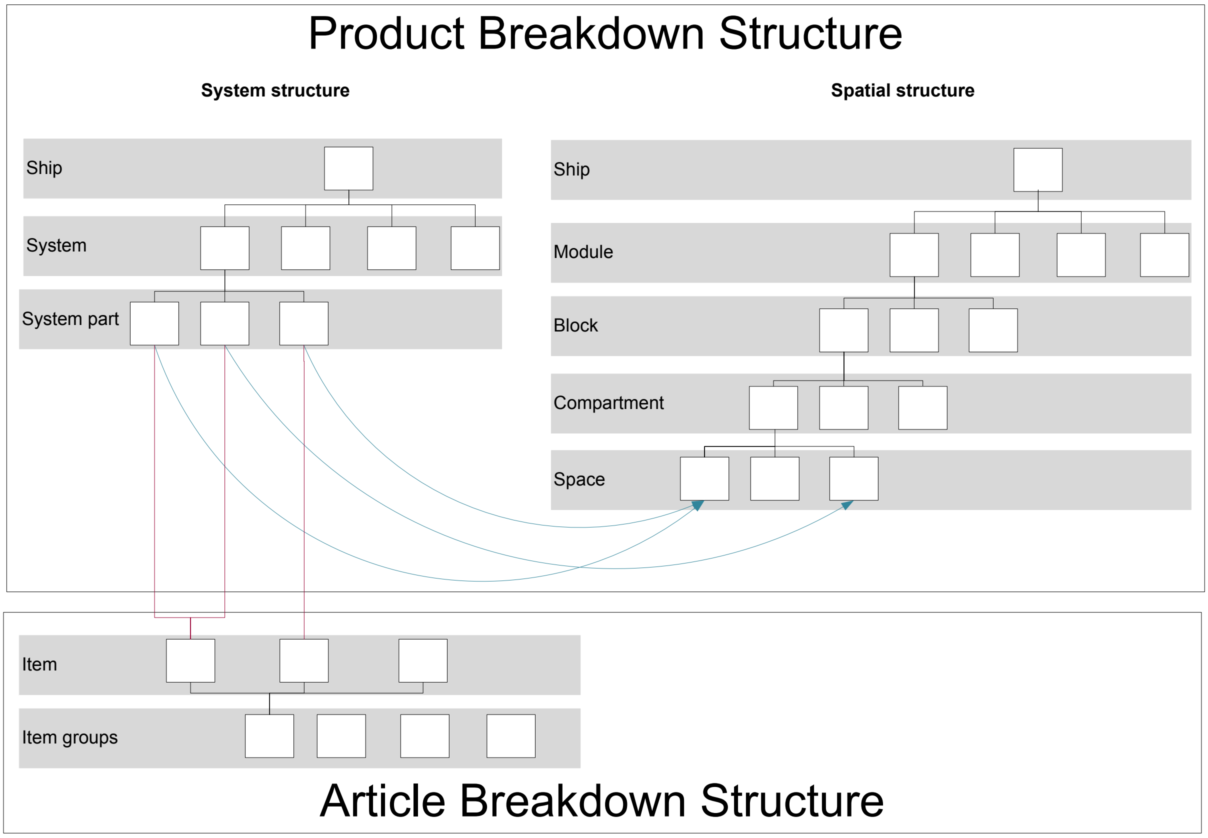


Figure 65 Product Breakdown Structure (PBS)

Work Breakdown Structure

The Product Breakdown Structure is the coat-rack of the Work Breakdown Structure. The WBS is a structure for all documents and activities. The activity number is identical to the document numbering. Almost every document and activity belongs to a system (part) or space (Figure 66). The owner of the document is a department of DSNS. Every department has an activity/documents group which is assigned with a number to the document.

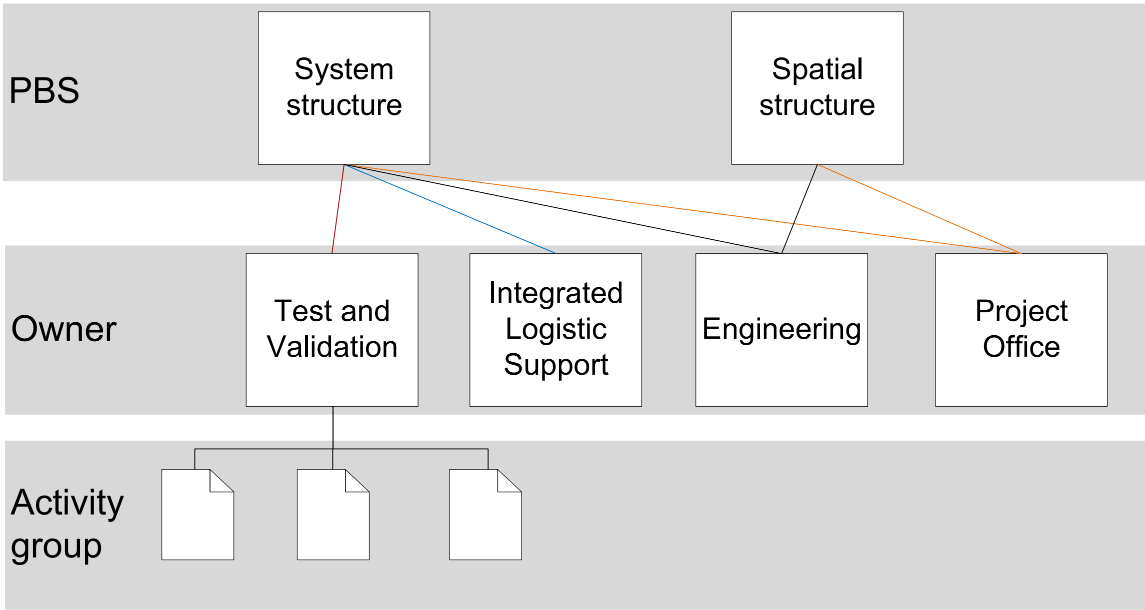


Figure 66 Work Breakdown Structure

Appendix D Data

Drawing sheets

Joint Support Ship

The Joint Support Ship is under construction and the release of drawings sheets will increase.

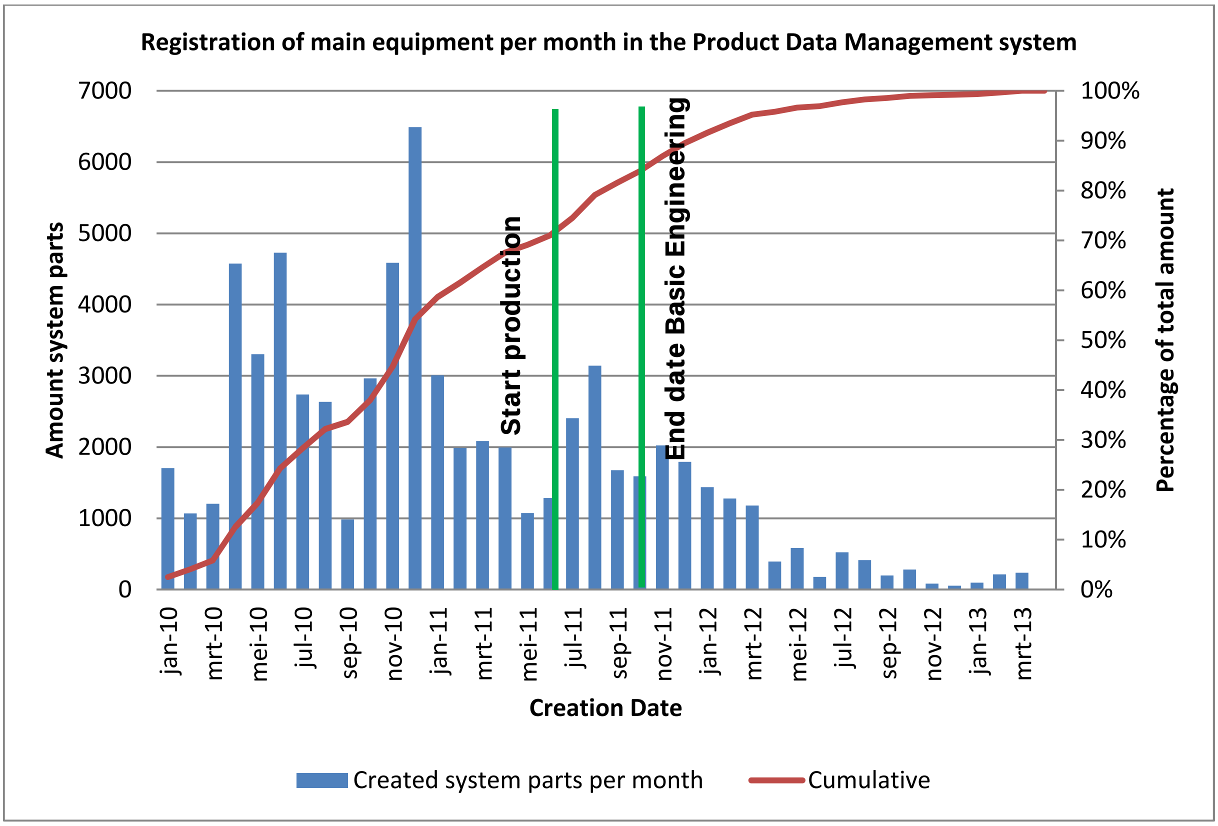
Count of Document No.		Revision A		
Activity	Fase	Yes	No	Eindtotaal
Basic Engineering	Arrangements	155	428	583
	Diagrams	111	330	441
	Plans & lists	193	197	390
	Calculations and reports	116	32	148
	Technical spec.	93	174	267
Totaal Basic Engineering		668	1161	1829
Detailed Engineering	Piping, Cabling and HVAC	1078	782	1860
	Structural drawings	1779	1728	3507
	Outfitting drawings & lists	394	723	1117
Totaal Detailed Engineering		3251	3233	6484
Production support	Production support activities	1		1
Totaal Production support		1		1
Eindtotaal		3921	4394	8315

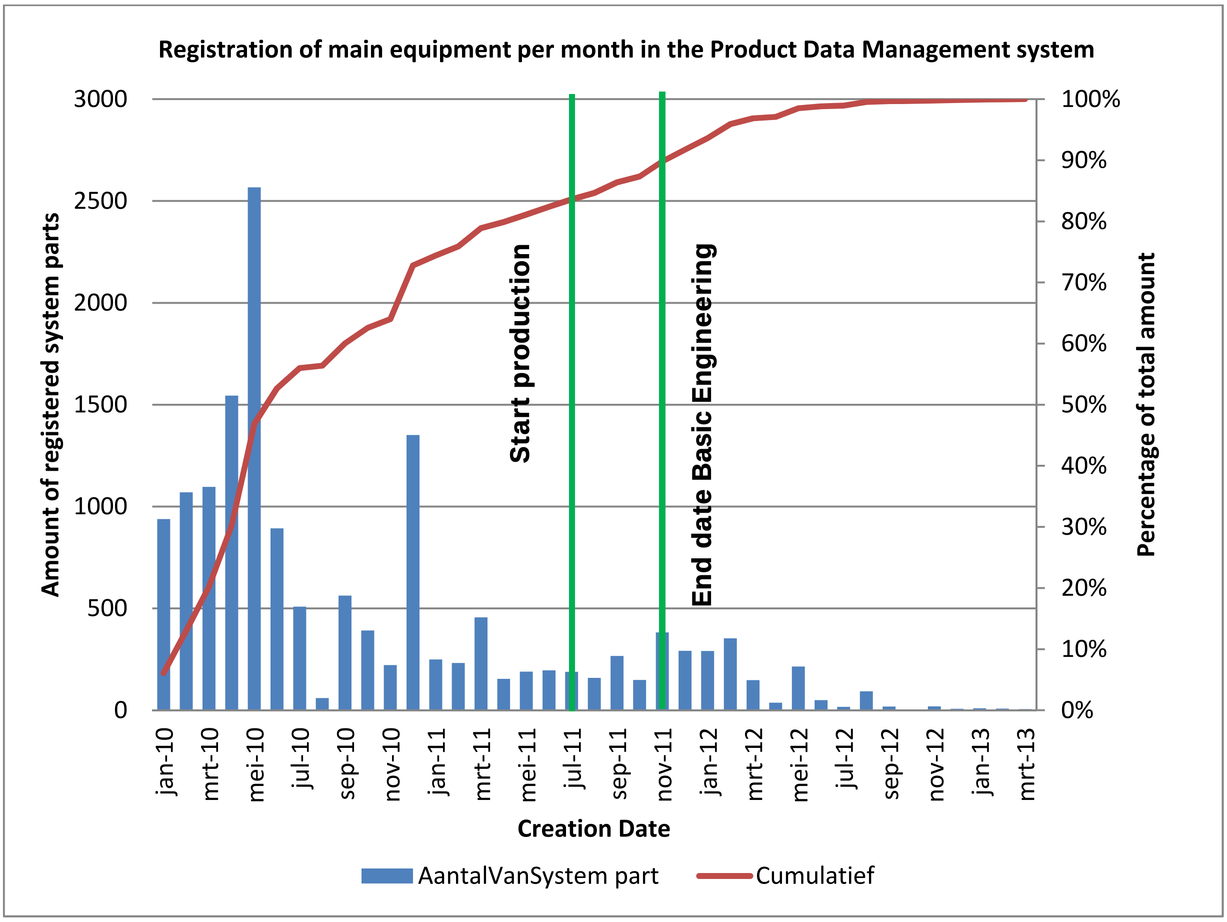
FFFM Combatant

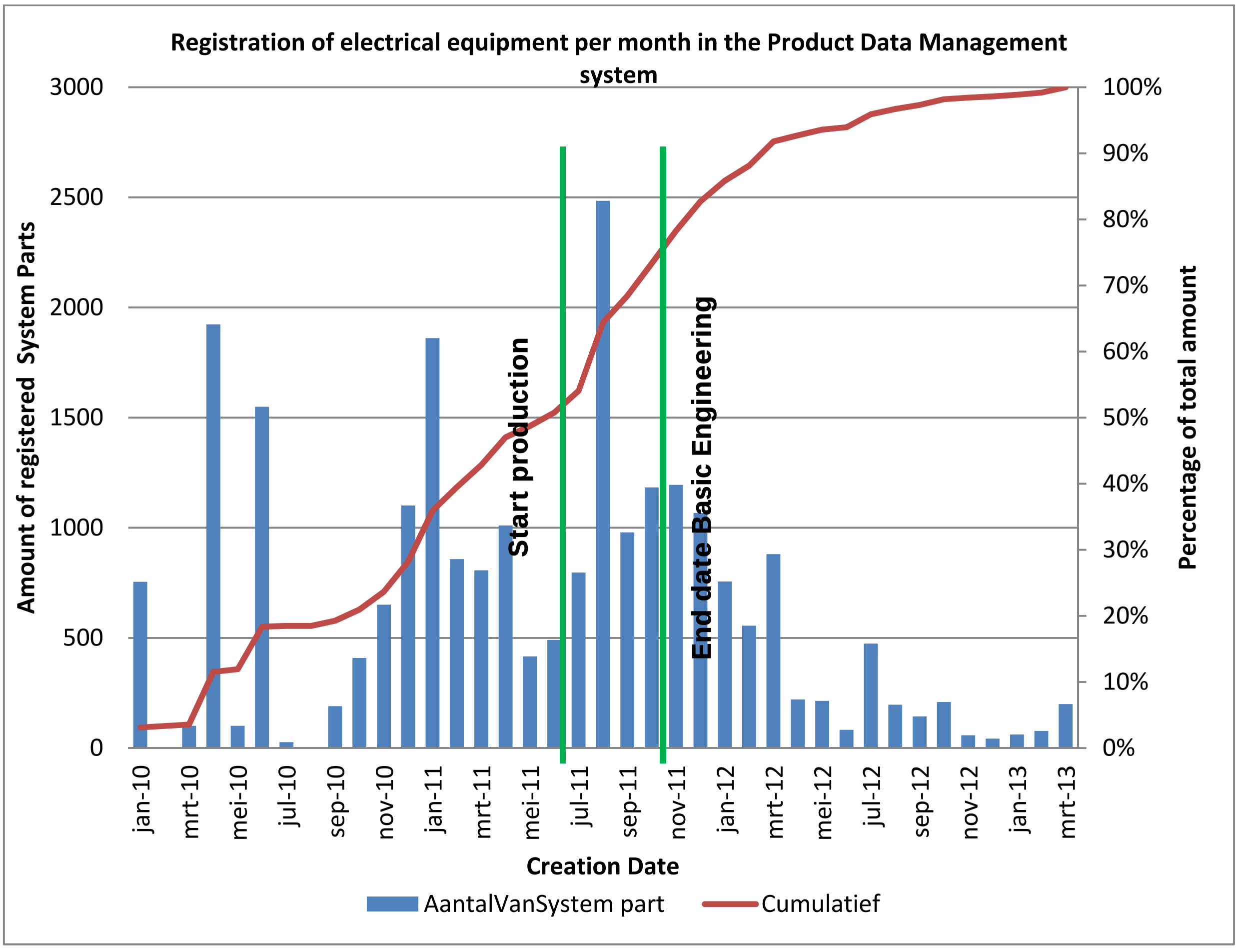
Count of DRAWINGNR. - No.DE DESSIN		Revision A		
Activity	Fase	YES	NO	Eindtotaal
Basic Engineering	Arrangements	70	152	222
	Diagrams	49	185	234
	Plans & lists	206	353	559
	Technical spec.	156	366	522
	Calculations and reports	13	292	305
Totaal Basic Engineering		494	1348	1842
Detailed Engineering	Piping, Cabling and HVAC	112	298	410
	Structural drawings	323	633	956
	Outfitting drawings & lists	255	571	826
Totaal Detailed Engineering		690	1502	2192
Production support	Production support activities	5	3	8
Totaal Production support		5	3	8
Eindtotaal		1189	2854	4043

Registration of system parts per month in the Product Data Management system

This data is an export of Teamcenter, a Product Data Management system. The registration date of a system part is exported and displayed. The export is taken from the Joint Support Ship, which is under construction. There's one issue of the project which have influence on the registration date of the system parts. The electrical subcontractor is contracted more than a half year later than Effective Date of Contract of the JSS. Therefore the registration of electrical components is started late, which can be seen in the third graph.




Registration of main equipment per month in the Product Data Management system
Amount of registered system parts
Percentage of total amount
3000
2500
2000
1500
1000
500
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Start production
End date Basic Engineering
jan-10
mrt-10
mei-10
jul-10
sep-10
nov-10
jan-11
mrt-11
mei-11
jul-11
sep-11
nov-11
jan-12
mrt-12
mei-12
jul-12
sep-12
nov-12
jan-13
mrt-13
Creation Date
AantalVanSystem part
Cumulatief


Registration of electrical equipment per month in the Product Data Management system
Amount of registered System Parts
Percentage of total amount
3000
2500
2000
1500
1000
500
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Start production
End date Basic Engineering
jan-10
mrt-10
mei-10
jul-10
sep-10
nov-10
jan-11
mrt-11
mei-11
jul-11
sep-11
nov-11
jan-12
mrt-12
mei-12
jul-12
sep-12
nov-12
jan-13
mrt-13
Creation Date
AantalVanSystem part
Cumulatief

Appendix E WBS structure for activities/documents

Eng. Phase		Activity group	orientation:
Basic Engineering	0	Plans & lists	system on ship layout
	1	Arrangements	space/comp/deck/system
	2	Diagrams	system
	5	Technical spec.	(part of) system
	9	Calculations and reports	system
Detailed Engineering	3	Outfitting drawings & lists	space/component
	4	Piping, Cabling and HVAC	block
	6	Structural drawings	block
Production support	7	Production support activities	system (0-group)
	0	Plans & lists	ship
	1	Arrangements	space/comp/deck/system
	2	Time schedules	
	3	Outfitting drawings & lists	space/component
	4	Piping, Cabling and HVAC	compartment or block
	5	Technical spec.	system(s)
	6	Structural drawings	block
	7	Production support activities	system/block/compartment
	9	Calculations and reports	system/block/compartment
	0	Test Plans	system
	1	Test Procedure	system
	2	Test Execution	system
	3	Test Report	room/system
	4	Acceptance Protocol	system
	5	Technical spec.	system
	6	Certificate	system
	7	Support activities	system
ILS Plans	0	Plans	ship/project
Basic Engineering	1	Survey and Reports	system
	2	*SPARE*	
	5	ILS (bestel) Specificaties	system

Appendix F Manufacturing Engineering

Current process

Within current transformation process the Detail Engineering will convert the 3D CAD model into 2D production drawings which is the input of job preparation. Job preparation will transform the 2D production drawings into manufacturing information.

As seen in Figure 67 the quality filter has been placed after the decode step. The position of quality control in the process will have some consequences.

At first the position will result in decoding production information which can be rejected by the quality filter. The rejected production drawings will be sent back to Detail Engineering for modifications. The decode step has to be performed only approved information. How frequent information is rejected after the decode step cannot be determined. In the current situation the reject information is already decoded and after improvement of the quality the decoding step has to be repeated.

The second consequence is the quality filter is applied on 2D production drawings. These 2D production drawings are displaying one subsystem of the product. The production process consists of different production steps: steel production, outfitting and piping. The 2D production drawings are representing one aspect of the vessel. Applying the quality filter on these production drawings results in checking all aspects of the vessel separately, whereby the interfaces between elements of the drawing sheets will not be checked.

The following example will explain this assertion. The foundation drawing sheet for steel production is checked for the quality of the available foundations on the drawing sheet. The outfitting drawing sheet is checked on the correct displaying of the equipment. A missing foundation will not be found with the current quality filter. It can be concluded that the standard for the quality filter is checking the quality of the content available on the drawings sheet and is not be able to check the quality of the total product as displayed on the several drawing sheets.

Revision management

The revised production drawing has been compared with the previous version. The differences are marked and are checked manual. These revised production drawings has been released and the production process has to check the revised drawings and has to decide how to implement in production process. This total process is a time-consuming process.

Manufacturing Engineering

The implementation of ME will change nothing into the transformation functions of the vessel design process, but will change the filling in of these functions. A few reasons for the implementation of Manufacturing Engineering will be mentioned. At first within current process the link between the manufacturing information and detail engineering will be lost with the decode step. The missing link will make it difficult to update the manufacturing information. The second reason is the improvement of the manufacturability. Concurrent work preparation makes it possible to change the production information to prevent difficult operations during production.

The concurrent processes shorten the throughput time of detail engineering and job preparation. It is also possible to use 3D manufacturing information during production, which will eliminate the decode step of the conversion of 3D CAD into 2D drawing sheets. This decode step is about 1/3 of the work hours spent by Detail Engineering. So the conversion step is time consuming and can be eliminated with use of 3D manufacturing information.

Therefore the quality filter is placed before the decode step. The new position requires an implementation of a quality filter into the 3D CAD model, which is not yet available. The quality filter has to be able to check the product quality of all aspects and the relations between the product aspects. The standard for this quality filter will be defined earlier in the vessel design process.
Within the new process the 3D CAD model will be the line of demarcation. The revised manufacturing information has to describe the necessary changes onto the product. Only the engineering change has to be communicated, and the responsibility of manufacturing information can therefore be transferred to the shipyard. The engineering changes can be best communicated with use of the 3D CAD model. The shipyard can use the 3D CAD model to make the new manufacturing.

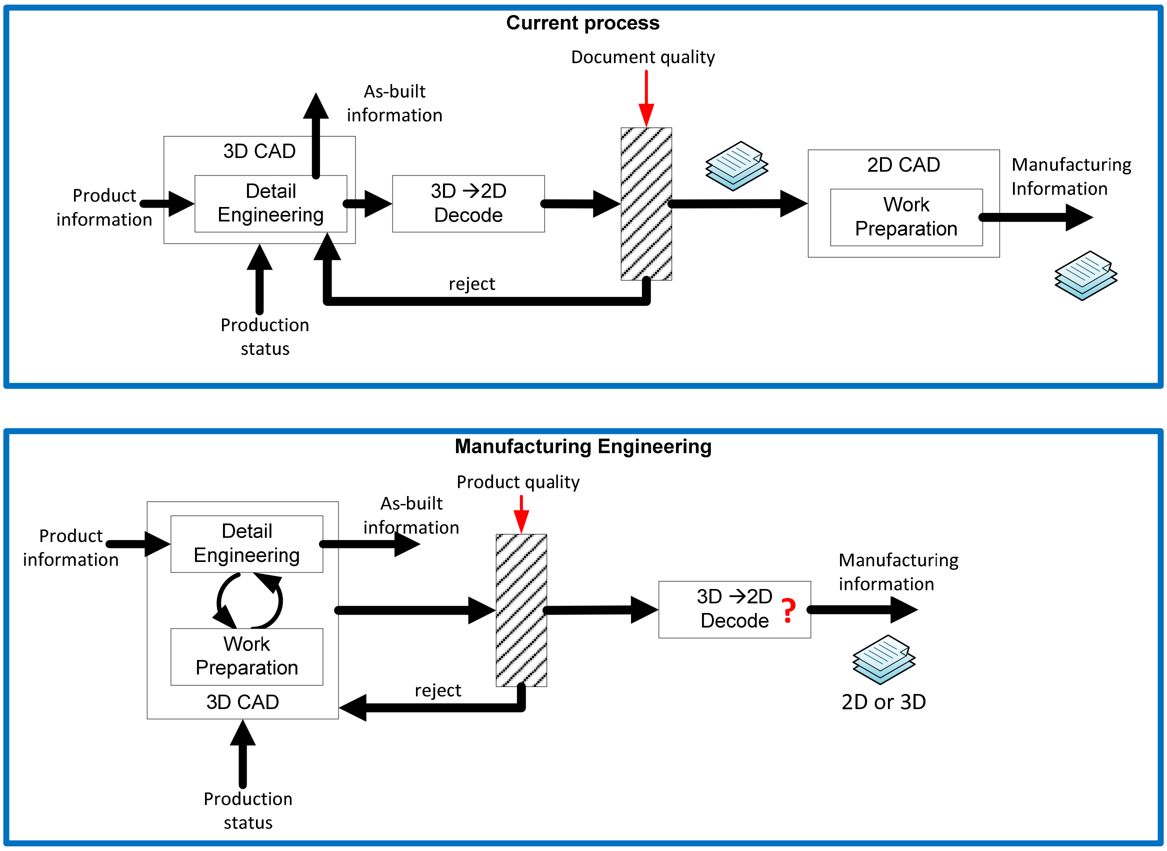


Figure 67 The implementation of Manufacturing Engineering