PLM and Classification Society Management in Marine Manufacturing Companies

Niko Ville Salonen

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Rolls-Royce Marine AS

niko.salonen@rolls-royce.com

Introduction

This study was started after 'Systems thinking and systems engineering' program arranged in Finland by group of technical universities and educational learning centre, Edutech, during 2011-2012. The program inspired to think could system modelling techniques give new ways of solving, proving and improving operational strategies and models in conjunction with PLM/ERP systems, Integrated Production Systems (IPS) in combination with more general techniques of UML modelling and other types of use case and data flow map presentation methods, and by using improvement tools such as lean six sigma 'toolbox'.

This study concentrates to identify specific Marine industry specific engineer to order based classification society management requirements and processes, which are known, but create extensive landscape of various certification processes influencing operational management of design, manufacturing, procurement and financial transactions, including invoicing and cost control to manufacturers like Rolls-Royce. This study focuses on modelling of different certification processes for configurable project specific products.

This study illustrated the same need and missing functionality from component manufacturer's point of view as Ehrler et al. (2007) [4] describes for classification society Germanischer Lloyd (GL), that currently these requirements are not sufficiently addressed by state of the art PDM/PLM software tools and solutions.

Classification societies have to manage product oriented structures (as designed, as built), associated analysis and simulation data (FEM, CFD) and manifold relationships to external part catalogues and material databases Additionally, the underlying information model has to be extensible and adaptable during production use in order to satisfy short term requirements from different certification projects.

The outcome of this study is setting a framework of studies carried out currently and in next coming 1-2 years trying to describe specifically manufacturer's business processes to meet the requirements from the classification society's, project management's and engineering change management's process point of view including the engineering to order logistical planning requirements for marine products. All these requirements are generic to all products, which are to be certified.

The key question for PLM from this study is could system modelling of dynamic systems give new ways of solving product lifecycle management system development issues by introducing modelling techniques to enable simulations to prove and select best option from possible technical architectures. The elements identified in this study should be compared with ISE information model AP239, Product Life Cycle Support (PLCS), known officially as ISO10303-239:2012 [5], is an international standard for the definition and exchange of product data needed for the long-term support of very complex products, such as ships. This model is again linked to various information models, including STEP geometry definition standards.

Approach

The approach used in this study is based on 13 years of experience working in marine manufacturing industry. During this time, first working with classification society processes in engineering at Rolls-Royce, in Finland. Later work has included developing different PDM/PLM solutions in local engineering organisations and during the last 3 years in central Rolls-Royce Marine PLM team enabling new methods and systems to comply with the varying classification society rules from the perspective of Rolls-Royce Marine delivering more than 150 different product types to thousands of customers.

The approach is taking account current ISO standards and commercial PDM/PLM/ERP tool capabilities, and articles and papers written within Marine industry conferences and organisations like ISSC. Statistical information from current IPS systems is supporting the practical knowledge. The conclusions are based on abstraction of true artefacts into concept generalisation.

Classification societies [6]

It is important to understand the relation between product manufacturers using different PLM/IPS systems and marine industry Classification Societies.

A classification society is a non-governmental organization that establishes and maintains technical standards for the construction and operation of ships and offshore structures. The society will also validate that construction is according to these standards and carry out regular surveys in service to ensure compliance with the standards. To avoid liability, they explicitly take no responsibility for the safety, fitness for purpose, or seaworthiness of the ship.

Classification societies set technical rules, confirm that designs and calculations meet these rules, survey ships and structures during the process of construction and commissioning, and periodically survey vessels to ensure that they continue to meet the rules. Classification societies are also responsible for classing oil platforms, other offshore structures, and submarines. This survey process covers diesel engines, important shipboard pumps and other vital machinery.

Classification surveyors inspect ships to make sure that the ship, its components and machinery are built and maintained according to the standards required for their class.

Today there are a number of classification societies, the largest of which are Det Norske Veritas, Lloyd's Register, Germanischer Lloyd, Nippon Kaiji Kyokai, RINA and the American Bureau of Shipping.

Marine vessels and structures are classified according to the soundness of their structure and design for the purpose of the vessel. The classification rules are designed to ensure an acceptable degree of stability, safety, environmental impact, etc.

All nations require that ships and other marine structures flying their flag meet certain standards; in most cases these standards are deemed to be met if the ship has the relevant certificate from a member of the IACS or EMSA. Certificates issued by the classification society on behalf of the flag country are also required for pumps, engines, and other equipment vital to the ship's function. Equipment under certain sizes is usually excluded from these certificate requirements.

In particular, classification societies may be authorised to inspect ships, oil rigs, submarines, and other marine structures and issue certificates on behalf of the state under whose flag the ships are registered.

As well as providing classification and certification services, the larger societies also conduct research at their own research facilities in order to improve the effectiveness of their rules and to investigate the safety of new innovations in shipbuilding.

There are more than 50 marine classification organizations worldwide. [6]

Principle certification requirements for component manufacturer

The principle certification requirements defined by the IACS include two main requirements that can be extracted and implied how product manufacturers need to comply in general terms against specific classification rules. The rest of requirements are focused more on ship building principle certification requirements. Classification process for key component supplier, manufacturer consists of:

A. A technical review of the design plans and related documents for a new vessel to verify compliance with the applicable Rules; [2]
B. Attendance by a Classification Society surveyor(s) at the relevant production facilities that provide key components such as the steel, engine, generators and castings to verify that the component conforms to the applicable Rule requirements; [2]

Generalizing above IACS certification rules and adding the requirement for material traceability

CLASSIFICATION CERTIFICATION REQUIREMENTS FOR MANUFACTURER ARE

- Satisfy international classification rules and documentation requirements in Marine industry products
- Satisfy material quality and traceability of every certified component

Design certification models

Design certification is one part of certification process. The IACS definition A. above describes the final requirement for design to be certified. The most used model as the IACS implies is the project specific "*case by case*" certificated design certification model.

Unfortunately the review process is not tuned from information flow and process point of view to level that customer delivery time requirement is always met. The demanding addition in ship building industry is the engineer to order

process, which in reality means that all requirements are not defined before the design process starts and in many cases even the manufacturing must be started before all requirements are fully known. This means that customer detail requirements are changing during the delivery process. For configurable marine products the definition of “product design plan for new vessel” is even more challenging as the vessel, generally ‘application’ changes the rules against the product.

Therefore classification societies have various design certification models to support and improve management of delivery time. The next more generic is “*product (design) type certification”*, which is in some classification societies named as “*design appraisal”* (incl. Lloyd's Register). The next level of approval is “*design type certification”*. Some classification societies also have “*special agreements”*, which two are mentioned below.

Special agreement (DNV) [7]:

In order to support efforts on reduced delivery time and to ensure efficient and correct certification processes, DNV consider it beneficial to establish General Certification Agreements (GCA) between manufacturers and DNV.

In such agreements the daily procedures for efficient processes for design approval and surveys will be laid down. Information and documentation needed and required by the two parties may also be defined and be part of such agreements.

Further, the agreement will also normally include commitments on transfer and sharing of information and experiences that are considered beneficial for the manufacturer and DNV. [7]

There are also concepts of certifying the entire PLM/IPS system in cases where products can be fully ‘configured to order’. Then the certification is done against the PLM/IPS systems and configuration rules within the system. In these cases the management focuses in the robustness of the system rules and to the change management of these rules. This level of certification is extremely difficult to obtain as the next sections will identify from the fact how much the processes vary. This type of certification is also business risk for the manufacturer as the system management becomes controlled also externally and the entire business knowledge is tight to the systems, and dynamical business changes or business strategy changes can not be easily adapted and systems modified.

Component and materials certification models

Component and materials certification is the second part of certification process. The purpose of this process is to ensure the quality and traceability of used materials and components.

This model contains again classification specific variations, but elements are based on international standards like the *"standard inspection documents"*, which is defined from ISO 10474 [8] (previous EN 10204-91) and EN 10204:2004 [10]. Classification societies have own definitions and names for these, but manufacturers refer usually to the ISO standards.

The material certification process starts from the combination of application and product specific rules. Some critical components require certification of material. These are identified from the basis of criticality of operability and safety of the application (vessel). Classification rules define specific inspection document types [7] for each component or functional component category, for example main propulsion shaft line components (including shafts, gears, bearings, clutches, couplings, propellers etc.).

The actual material certification process requires specific *"samples"* and *"test reports"* performed and documented by defined authority, which again can vary, and finally including *"material inspection"*, also having element of options which party can perform the inspection.

Certified components and materials can be traced by unique item codes or by item serialization. Serialization has been more used and rational way of managing item data in ERP systems. Materials are serialized *"by lot"* and components requiring certificate *"by unit"* or *"by lot"*. By lot means the material is traced to a level of raw material batch. By unit means that the component is traced to level of every unit produced.

Most used component/material certification is *"case by case"* certification as is for design approval. Manufactures and classification societies are trying to improve the process performance in different ways. One of these methods is by *"group certification"*, which is not fully standardized approach from the fact that sharing the certification is not improving classification society's individual profitability of their business. From customer's, ship builder's and manufacturer's perspective this would be excellent way of improving the process as it increases flexibility to use certified materials and components. This is another topic for the financial management and dynamic systems modelling of the classification society management.

More used classification society specific process model for manufacturing is called *"type approved manufacturing process"*, which is defined as part of *"type approval"* in some classification societies (incl. Lloyd's Register). In DNV this approval model is called Manufacturing Survey Arrangement (MSA) [7] in Lloyd's Register of Shipping type approval term is used for overall approval of design and manufacturing, and *'design appraisal'* is the term used for design certification.

In general classification society type approval requires companies to be certified with ISO 9001. This rule applies to all type approvals.

Product certification process

Product certification is the top level certification that links the product to the actual application, ship, oil rig or submarine. Type approved components or products must always be still documented against the application and classification societies will review that the type approvals are compliant within the application and usage of product in it. However, when configuration management of product is done properly within the limits of the type approvals, manufacturer can process the product certification efficiently by extracting and collecting the documentation from the PLM/IPS system.

"Manufacturer's declaration" is the first principle assurance of compliance from the manufacturer, that each installed product will be according the specific classification society rules.

The product certification process usually includes system and assembly level testing. The classification society inspects onsite that the specific serialised manufactured product and certified documentation is according the rules for specific application. When product and documentation is according specific rules the inspector will issue unit certification and product is ready to be installed to the application (vessel etc.).

From manufacturer point of view the product is now ready to be shipped to shipyard to be installed to the specific application. This study does not include the classification processes in the shipyard. This process includes also the sea trials, but this level certification is against the entire application and main aspects of manufacturer classification processes have been performed before this lifecycle phase.

Financial invoicing and costing models

Financial aspects of classification society management are not part of scope of this study, however it is important part of overall evaluation of classification society management and even more important for understanding and improving using dynamic system modelling and simulation methods.

The complexity of classification processes makes recording and managing cost difficult based from two different aspects. As the rules itself are complex and variable, so are the financial transaction models. First point is that invoicing is not standardized among classification societies and there are several agents causing additional variation to the cost collection and invoicing process. This again means that manufacturers can not record accurate classification process cost and often even invoices against specific items in ERP systems. Very often the cost is recorded for the delivery project or even worse on yearly basis. Defining standard costing models and processes for financial invoicing and costing must be part of future study to be able model and simulate the system dynamics.

Current product life cycle standards for marine and classification societies

The standard exchange ship Product Data Model is STEP (ISO 10303). This Application Protocol shares some modules with the AP239 devoted to Product Life Cycle Support (PLCS) that was published on 2005 and latest 2012. AP233 is the standard for Systems Engineering Data Representation. The objective is to provide the functionality defined in the shipbuilding application protocols using a combination of STEP AP239, AP214, and reference data libraries.

DNV has presented a product model specifying a standardized vessel description for class work (Vindøy, 2008) [3] based on ISO 15926 and DNV's own "ships functional" classification hierarchy.

Classification society approval processes in shipbuilding introduce additional and specific requirements for information management systems to be used in the ship design process. ISO 10474 [8] defines the inspection documentation requirements adopted with modifications to classification societies. ISO 9001 is quality standard that most marine product manufacturers have adopted also to support ways to improve the classification society certification processes.

Different engineering change management approaches which form the basis of these functions in PDM systems are listed. The most relevant ones are: Quality management - Guidelines for configuration management (ISO 10007), Institute of Configuration Management (CMII), Workflow Management Coalition (WfMC) and the ISO 10303 Standard for the Exchange of Product Model Data (STEP).

Product lifecycle view of certification processes

Below a simple component based certification process (Figure 1.) is described in SIPOC (Supplier – Input – Process – Output – Customer) process model. The process is also the most often used *"case by case"* classification (meaning all documentation and process is re-used and each step in the process is performed again and again for each delivery project for specific customer). Any dynamics (including feedbacks, other loops, delays etc.) are not considered in the SIPOC model. The SIPOC does not either consider the original design requirements that have been identified against the product definition.

The SIPOC process figure's key elements are creating design documentation that is reviewed by classification society authority and stamped as approved. Then the manufacturing process is inspected based on rules and against the approved design documentation (the meeting point of design and physical product).

This process is performed to all components defined requiring certification by the specific classification society rules. Final product/system (Unit) inspection is collecting all related approved documents and product certification is given to the equipment.

This process is followed for every product delivered to customers. There are two very specific differences compared to other businesses (car, aero manufacturing): Rules change based on specific classification society (and there is several as mentioned in the chapter Classification Societies) and the other difference is that final inspection is done by specific classification society inspector for every sold unit.

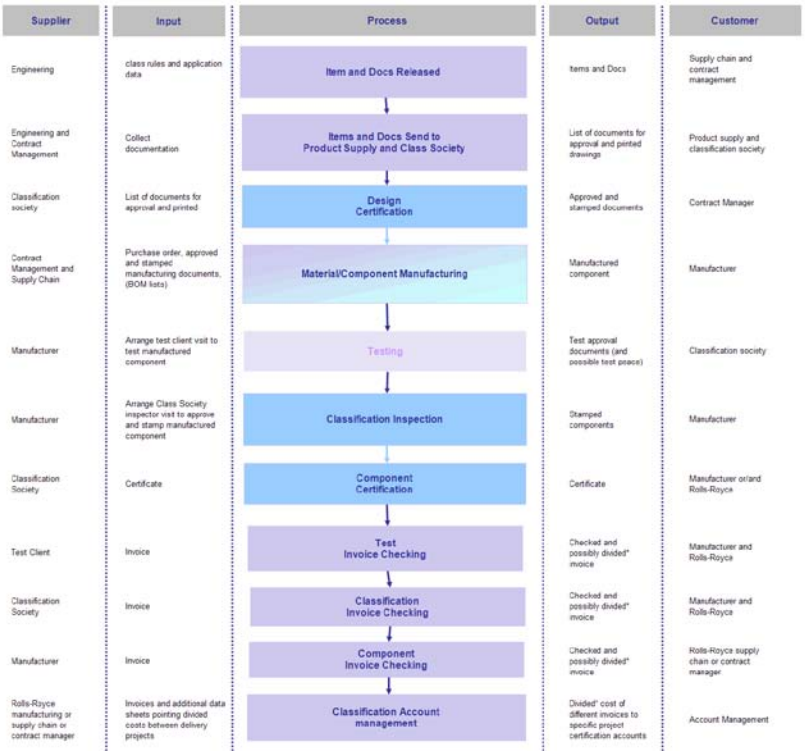

Fig. 1. SIPOC for *'case by case'* classification process without any dynamics

When manufacturer is operating by *"case by case"* basis and using manufacturing suppliers the flow of information, material and people can be illustrated as in figure 2. This figure shows also the 'happy path' without any additional loops, which may occur in the process.

The link from certificate management to the supplier or to internal production is critical flow connection point of documentation information to physical product flow. These connection points and the dynamic flow of information and components/material is causing that *"case by case"* certification does not work, main reason for dynamics is that both flows contain variations of loops and delays.

There have been situations, where classification societies request the documentation package of the entire product to be sent only when fully complete, which again fights against the ETO process principles. It is fully understandable from classification society point of view, that it would be easier to review the documentation as one fully defined package rather than one evolving package of documentation to obtain the product approval. However the business requirements do not make this easy or practical.

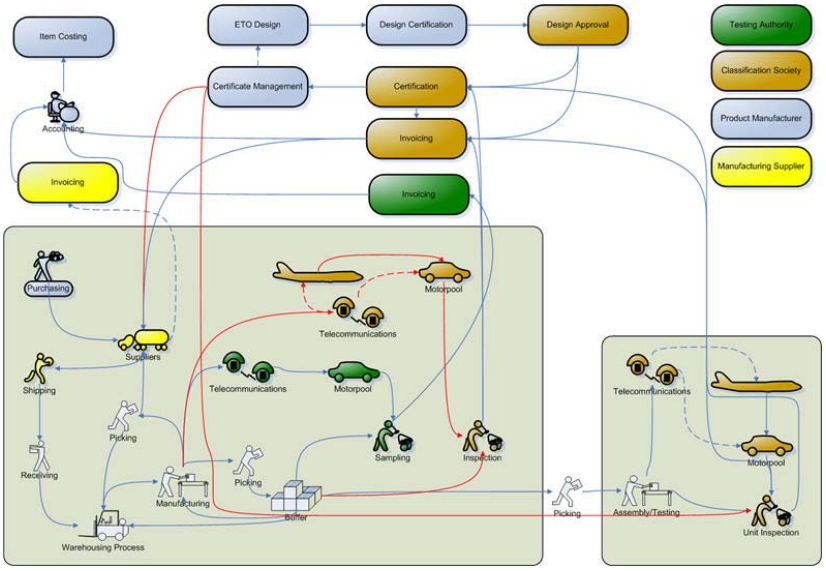

Fig. 2. Information and material flow in 'case by case' delivery process

In comparison for type approved design and certified manufacturing process the flow is presented in figure 3.

The situation of *"design type approved"* documentation information flow in figure 3 would show in stock flow model differences from *"case by case"*. The difference is, the design certification is already obtained and the data can flow through the purchase order or production order process information flow and not as separate information flow. Obtaining the Product (Unit) level design approval is easier as the package of documentation can be provided early on the process.

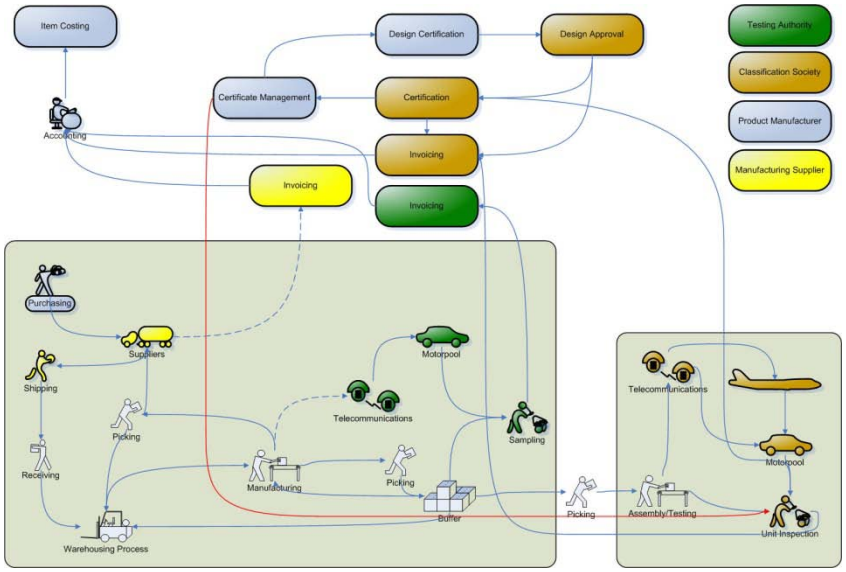

Fig. 3. Information and material flow of type approved and manufacturing approved process

Theoretical link between PLM and Classification Society management

The theoretical relation between PLM and Classification Society management can be identified by systems thinking (including many systems engineering principles) and information science levels. Operations management theories could be linked also between PLM and Classification Society, but are out-scoped as systems thinking and information science are deeper principles that this study concentrates.

Using definitions: openness, purposefulness, multidimensionality, emergent properties and counterintuitive from Jamshid Gharajedaghi's, 'Systems thinking, managing chaos and complexity' book [11], the link between systems definitions and certification process can be achieved.

The certification of component within an application has direct correlation to open systems principles, where the certification requirements can be understood only in the context of the environment, the ship and product located in specific function. The certification changes additionally between classification societies, but these differences can not be reasoned directly, but can be seen as variation or immaturity of understanding systems.

Purposefulness can be seen of understanding why certification is happening. The value-guided system can be identified in this study by challenging the current

models, especially the ‘case by case’ certification process based on understanding the what, how and why of the system, classification society management.

The plurality or multidimensionality of classification society management and certification process can be identified in function, structure and process levels. The system ship-product-component and certification process has several functions, for ship owner it is means to manage the insurance cost, secure the quality of product, for classification society it is means to earn money and improve global safety of sailing ships, and for component manufacturer it can secure easy entry to market and help identifying principle rules that shall be complied when designing and manufacturing products to commercial marine ships. The plurality of structure for certification required components and an entire product structure are closely linked between the PLM and Classification Society certification process. The plurality and ‘equifinality’: a final state can be reached from same initial conditions by number of routes. Certification processes can be seen from the differentiating from causality by ability to certify the product with various certification methods.

Emergent properties of classification society certification management could be the overall satisfaction of all parties in the certification process, ship owner, shipyard, classification society, manufacturer and others. This satisfaction will evolve the systems behaviour over time.

Counterintuitive behaviour can also be seen part of classification society management. Only taking one example is component manufacturer’s overall cost management. The cost structure and behaviour of certified components for many manufacturers can not understand if there is not enough knowledge how the system behaves with various dynamical relations. This can lead to mistakes from ‘assuming’ that changing one parameter of the system would lead to positive reaction, but actually result can be opposite, negative increase of overall cost.

Systems engineering and it specific area of requirement management is core part of PLM principles and also PLM systems. The classification society rules are requirements and very much structured requirements.

Information and library science’s classification, collection, manipulation, storage of information is field, which is basement for researching computer science, database systems and overlaying PLM applications. Turning the conceptual certification process and information principles identified in this study will eventually lead to defining information architectures, information management and information retrieval concepts for the PLM (IPS) systems.

Principle impacts to PLM and entire IPS

Previous classification rules, including design, component/material and product certification creates complex process and data model requirements to manufacturing company, especially when same product is certified to different

classification societies and product is used in different applications (ships, oil rigs etc.) or/and having different usage models.

The engineering principle of form, fit and function (FFF) definition can be jeopardized by this if items contain data of classification society specifics. From engineering perspective keeping product definition purely compliant to FFF reduces enormous numbers of variants of items. From engineering point of view and from management point of view isolating the item definition purely into FFF, means that the item (raw material, component, assembly or product) must be maintained as such trough it's whole lifecycle from cradle to grave. To the question how the requirements can be met without jeopardizing true FFF item definition is explained next.

The classification rules for manufacturer can be identified as requirements same way as actual customer requirements are defined. The requirements can be divided to into categories described earlier. The requirements are also assigned to different lifecycle phases of the product. Common requirement and domain is that requirements are including the application domain, which creates need for conditional requirements from manufacturer point of view manufacturer wants to use the product in different applications. For configurable products this creates more complex data model requirement as there can be configurable modular products as the product (unit) level product definition is very generic. As described in earlier study [9] the "*unit concept*" model can be used as the representative item against the requirements, before actual delivery specific item is created.

Based on statistical study in azimuth thrusters the same component can have different certification models (documentation and process requirements) already in the generic product structure (also called as 150% BOM) definitions. The variation can increase when generic product is configured to physical product structure definition (100% BOM). This fact and the previous application and unit level definition based metadata combined define the abstraction into "*conditional occurrence tree based requirements*". This means that the specific component occurrence can have conditional requirement against the classification society management process.

The application domain requirements can be identified for design, some for documentation during product design, some specific for application engineering phase, some for actual manufacturing processes (inspection, sampling and testing, certification), which again all can contain documentation needs and keeping records. The requirements can be pointing to different certification types based on application or usage in application. Managing documentation specific for each application (engineer to order delivery project) for specific system/component/material creates own data model requirements.

Example of azimuth thruster's product structure and conditional requirements is shown in figures 4. and 5. In figure 4, azimuth thruster's (unit) structure is having parent application (vessel "Tug") and the azimuth thruster is containing one branch of configurable modular product structure. The parent child structure has deep sub-module structure, which are also configurable and the lowest level components have sub structure of pre-fabrication components and finally raw materials.

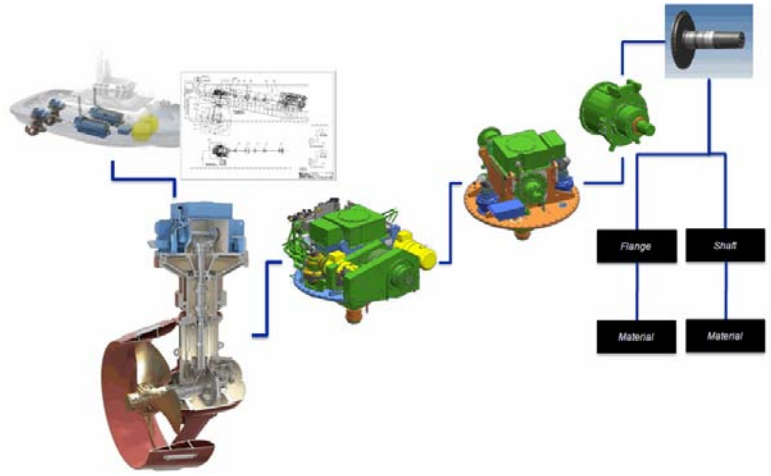

Fig. 4. Example of Azimuth Thruster product structure, installed in a harbour tug

In figure 5, azimuth thruster (unit) structure and the parent application (vessel "Tug") have extractions of metadata, shown in green arrows. The actual requirements are linked as previously defined not against the components (Shaft and raw materials), but against the occurrence of the components. The conditional rules are illustrated with IF-AND clauses. The red arrows mean positive outcome "Yes" and yellow are negative outcome "No". The black arrows are conclusion links "To Obtain", which can link between requirements, representing the sequencing, or to artefacts (documents), which will be received or created by the manufacturer.

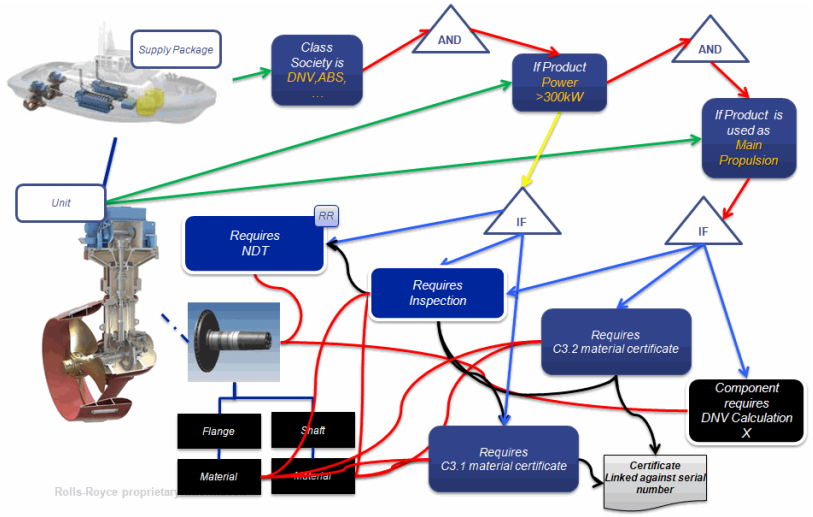

Fig. 5. Example of conditional requirements against the shaft

The requirements (rules) themselves are also moving target for manufacturer. The rules are revised and classification societies identify the effective date for each version. This is specifically the Rules effective dates, which are defined by classification society. The rule is linked to requirement defined by the manufacturing company. One reason for separating the rule and requirement is that many rules are not precise and specific and manufacturer sometimes must take interpretation of the rule. This happens also in real cases, when different inspectors from same classification society interpret rules differently. This type situation can be recovered from, but the delivery process can be impacted by delay and loops of communication between manufacturing company and classification society.

Businesses can not react as fast even classification societies identify the rule change dates early in advance. Manufacturers main focus is bringing value to customers, which means the customer requirements drive the changes in products. The regulations must be complied, but the phasing of design changes do not match.

Marine manufacturers work according the ship building project principles and timelines. The sales phase and contracts are long processes and the commitment to customer requirements need freezing classification society requirements in certain point to be able to deliver product in time according contract. This means that item definition and the class society requirement relation has also effective date.

Linking requirements based on classification rules from top application to low level components and materials need conditional requirements as the rules are not standardized. The product and application relation and application performance characteristics make some requirements not valid or not active. The difference of not valid and not active is quite different by means of data model if the item definition is kept intact. The linking of the requirement can be done to several items and the validity of the requirement is conditional of the combination of characteristics.

In IPS landscape the active requirements and only active (delivery specific product configuration) must be transferred to resource planning system for manufacturing integration to inform supplier or internal manufacturing of the testing and inspection and certification requirements. Again avoiding multiplying actual FFF items creates specific need to manage the information until As Built configuration has been created. There can be several methods how the information of requirements can be transformed to documentation package objects and processes and how the information is transferred to ERP systems. These models are often company specific models not described in this study.

Thinking of dynamic system models

Static modelling as done in this study is not enough to develop integrated production systems (IPS) and select the optimal operations strategies. One of the key questions developing and maintaining these systems is overall IT cost against the achieved business benefit.

The classification society management process has many feedback loops and delays all influenced by different certification models or combination of models used by the business. Understanding the dynamics and simulating the options can first of all improve the decision making of certification strategies, but also what IPS functions should be developed and which order.

Defining the relations of other manufacturers is required for the dynamic business system model. From modelling the dynamics the behaviours and sensitivity analysis could indicate and help PLM and IPS developers to understand what system configurations must be in place to create solution to include flexibilities for business environment changes in short term and in long term.

Conclusions

This study defined the principles of classification society rules for a product or component manufacturer in marine business sector. Different certification processes were identified and described and single component classification

certification process and, data and material flow models for *'case by case'* and *'type approved'* were illustrated.

The classification society rules define conditional requirements against the product definition and production process definition. These requirements are linked from the top level application (vessel) and product (unit or concept unit) through to lowest level of components and materials. The documentation requirements are from the original designs or design templates to the application engineering phase documentation for specific application. The rules vary also in the manufacturing phase, requiring different traceability levels for item to various testing and inspection requirements, including documentation.

The item traceability with related documentation for specific application starts from delivery project. In configure to order and engineering to order type business, highest level structure items can be used to carry documentation for the child items, however this is not optimal solution for learning and lean organization. Adding folder type objects or manufacturer's internal serialized objects having traceability to enabling addition of documentation against the FFF items improves the information capture and use or re-use of existing data improves.

Without question various system configurations can be developed to facilitate solutions for the IPS applications to manage classification society data, data flow and processes as explained above. As the classification societies are not working in standard models (requirements nor financial operations) manufacturers must base their PLM and ERP strategies on their own product portfolio and positioning in the market sector creating flexible solutions. Unfortunately this creates more complex unique technical solutions for each manufacturer. This influences selection what operational strategies and system development strategies should be taken to simplify and optimise the operations to improve internal processes and reduce overall cost of classification society management.

Discussion and further work

This study has recognized several improvements what IACS could focus on. Standardizing the rules of classification societies and including rules for standardizing financial management, especially invoicing of the classification certification process. It is understandable that this type of improvements require long time and involvement of international standards like ISO, major insurance companies and entire shipping community, including ship owners, ship operators, shipyards and the logistical chain to raw material producers. Some of topics have been raised already in the European Union organisations.

This study brought up need for studying the financial invoicing and costing models of the classification society certification process based on the fact that the

cost of classification society management is business critical parameter. This study has also been completed, but official papers or articles have not been published. More important for manufacturers is to model, analyse and understand the system behaviours and ways to control and optimise the overall performance of the company. The types of dynamics, which have been presented in this study, are also being modelled and later simulated with tools like Vensim [1]. This study is still ongoing.

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