Maintaining Quality In The Supply Chain

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SYNOPSYS

This paper looks at the challenges of maintaining design intent and the quality within the naval supply chain and how it affects the supplier, builder and operator. The supply chain plays a critical role in the safety, reliability and operational availability of a naval asset.

Naval ships and submarines are complex machines built and operating in a high-risk environment to exacting operational requirements. Ensuring design intent is met within the supply and procurement process during build and through life maintenance is paramount in managing the inherent risks.

Design intent is usually based on assumptions regarding the product quality, in some analyses designers assume components are perfect. However, in reality, product quality is a function of the raw materials, process, procedures and workmanship applied by the supplier. It follows that achieving the required level of quality within the supplied products and hence meeting design intent is one of the key elements on which a naval vessel is built.

The challenges in assuring that quality levels, and hence design intent, are being achieved are many and varied. There are direct aspects to be specified and managed, such as: strength, integrity and weight; plus, transverse aspects such as shock, noise and vibration or product security. Product security should be considered in its widest sense and include security to prevent manipulation plus security of supply for long term builds and through life where specialist components are used.

A well-managed supply chain will address such issues and bring benefits for both supplier, builder and operator. Well-managed supply chains bring clarity and consistency to the requirements and responsibilities of all parties are clear. They provide assurance that design intent is being met as well as creating opportunities to streamline both the manufacturing and supply chain processes to provide opportunities for cost savings.

INTRODUCTION

Supply chains can be very complex and long, with multiple parties, sub tiers and countries involved. At each contractual step, there is a translation and interpretation of requirements which can and does go wrong, leading to repair, replacement or worse still, unidentified embedded defects. Manufacturers with good quality process have been known to accurately replicate mistakes identically in every single manufactured component. In addition, some parties will seek to take advantage and supply counterfeit

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items into the supply chain. Techniques such as supply chain mapping and supplier qualification are used to control these aspects, however issues still occur, and a level of product verification is required.

The level of effort expended to verify that the required level of quality has been achieved will vary. It is not economically viable to apply the strictest verification regime to every component, so an assessment of risk is required, to determine the impact of equipment or component failure on system performance, safety and integrity. Once known, an appropriate level of quality requirements can be defined, and a corresponding level of verification implemented.

In this paper we discuss the key issues for naval supply chains. In particular we look at the advantages of improving quality in the supply chain through product verification and the resultant rewards for the Builder and Navy. The tools and processes which can be employed in ship and submarine supply chains are described to achieve the goal of assuring design intent with appropriate assured processes. This will improve manufacturing efficiency and a reduction in the supply of defective or below quality products, with the consequential benefits of lower through life costs, increased product reliability and an improved naval asset operational availability.

BACKGROUND

To understand the complex nature of marine equipment certification we need to be aware of some of the background. Classification rules have adapted to the evolving nature of shipbuilding and its supply chain. They develop to support new designs, materials and production methods, to ensure they remain relevant and fit for purpose, to ensure safety and reliability for the marine industry.

In the same way, the methods of achieving and demonstrating compliance to and with the standards or regulatory requirements has also changed and developed. Certification, the conclusion of the verification process, which confirms compliance of a process, or product has also changed and developed over the years. As well as reflecting new technologies they also have to respond to changing international government and regulatory requirements.

Initial requirements for certification of materials, manufacturing processes and equipment were defined by the classification societies who set minimum requirements for material properties and building standards. Some early examples are provided from (Ref 1)

> *VESSELS BUILT UNDER A ROOF.*
> *An additional year will be allowed to vessels built under a substantial and efficient roof, kept in good repair, and which extends on each side beyond the vessel's breadth, and beyond each of her ends to an extent equal to half her midship breadth.*
>
> *QUALITY OF IRON, MAKER'S NAME, AND WORKMANSHIP.*
> *The whole of the iron to be of good malleable quality, to be capable of bearing a longitudinal strain of twenty tons per square inch, and all plate, beam, and angle iron, to be legibly stamped in not less than two places with the manufacturer's trade mark, or his name, and the place where made.*

The more modern requirements have a similar level of assurance and requirements for provenance (Ref 2)

> *Materials for metallic castings and forgings for Class I and II piping systems are to be produced at a works approved by Lloyd’s Register (commonly referred to as ’LR’) and are to be tested in accordance with the Rules for the Manufacture, Testing and Certification of Materials, July 2019.*

Subsequent to classification, International Maritime Organisation (IMO) requirements have been defined, agreed and adopted by many countries, this brings a further set of requirements for design, construction and equipment certification.

An additional set of requirements that flows through the whole process are the international and national recognised standards raging from the ISO, IEC, DIN and British standards. These national standards are well established and often cover more elements of the design, manufacture and test requirements than an IMO or class requirements do. In fact, classification recognises this and where appropriate will accept a certification to a recognised national or international standard. An important caveat is that the standard needs to be appropriate for the end use. Many international standards do not include marine operating conditions e.g. vibration, or ship motions.

Finally, the European Union's MED process was introduced to standardise the technical and manufacturing process assessments and combine them together in a quality scheme to provide product verification and assurance to the end user that a product is designed, manufactured and tested to a minimum acceptable standard. While this became mandatory for all EU flagged ships it is now established and is recognised and used world-wide. The process is only applicable to equipment within the scope of IMO conventions for which there are test requirements, generally pollution, lifesaving, fire, navigation and communications.

A note of caution concerns the quality standards that refer to a company's quality assurance process and procedures. These are typically the ISO 9000 series. While they demonstrate a level of quality assurance, they cannot be accepted as confirming technical requirements for design, manufacturing or testing. Similarly, CE marking is a manufacturers declaration of compliance with EU regulations, which may not be of sufficient scope and are not acceptable where 3rd party product assurance is required.

Demonstration of compliance, the resultant certification and method by which it is achieved is driven by the commercial activities within the marine industry. With the ever increasing need to drive efficiency more than one way to achieve compliance has been developed. Suppliers will have generally settled on a process that meets minimum regulatory requirements and the majority of their client's expectations. Low procurement volumes usually mean that this will not usually include naval requirements.

SURFACE SHIP PRODUCT VERIFICAION

Over the last ten years, there has been an increase in the use of classification societies in naval ship procurement. Ship classification provides a risk based assurance regime for equipment in the supply chain as well as for the design and build of the ship. Increasing levels of assurance are applied to high risk and safety critical components. The system has developed over the last two hundred and sixty years evolving as technology and manufacturing processes have changed. It is, to a certain extent, taken for granted by the commercial marine industry though suppliers are very familiar with the requirements needed to get their products into the marine market.

Classification has a defined scope of application, naval ship class is different to commercial ship class, class notations change the scope of application. It is important to determine the elements of a ship design that fall within the scope. A key step is to map the scope of Classification against the project's work breakdown structure, this is typically based on weight groups (Ref 3).

Categorisation

For those equipment items within scope, certain assurance categories will apply. In the commercial Ship Rules, systems and the equipment they contain are categorised as essential or non-essential. The essential category is applied to those that are: controlling safety hazards, required to move the ship or having stored energy i.e. a pressure vessel. Lloyd's Register's Naval Ship Rules use a categorisation of Mobility, Ship Type and Ancillary based on the function they perform and they also recognise equipment which may pose a hazard to the crew. IMO Conventions have certification requirements for essential safety items and equipment protecting the environment. The categorisation can have a profound effect on the assurance process used by the Classification Society (Ref 4). The categorisation essentially highlights the risk a system poses to the ship, people or the environment.

Naval classification is based on commercial classification and sometimes the systems and equipment considered essential may not match a naval client's expectation. Whilst the "float and move" elements are addressed, the level of assurance required from a classification society may need to be increased to provide the necessary level of integrity to support the naval ships "fight" functions.

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Transverse requirements

Naval ships have transverse requirements, these are performance requirements which apply across the ships systems. They include issues such as shock, operating angles, ingress protection, temperatures, humidity, smoke, toxicity, vibration, EMC, noise. They are derived from the operating environment, signature or vulnerability requirements, often different from the commercial marine baseline. They normally require additional testing and verification. Whilst the commercial marine market has agreed a common operating environment (Ref 5, Ref 6) The naval community has not and is unlikely to, because many of these transverse requirements provide the navy its military advantage.

For naval projects, the standards may be tailored to include transverse requirements or, to modify the commercial requirements to suit the naval operating context. Both transverse and tailoring requirements need to be transmitted down the supply chain to all relevant tiers, usually via a series of equipment specification.

Assurance levels

Classification rules have divided the systems and associated equipment & components into different categories, each has its defined role and function and a corresponding level of importance or associated risk. This in turn demands varying levels of assurance and rigor to which a design, manufacturing, quality, function and performance is scrutinised and tested.

The Rules specify a number of assurance methods for equipment. The higher the risk posed by a system or its equipment, the more stringent the assurance process and product verification requirements. There are at least nine levels of product verification or certification defined within a classification society rule set, the verification activity uses a variety of acceptance standards and processes. To try and assist with sorting out the complexity and give clear guidance on how to approach the complex certification question, tools and guidance have been developed on several recent projects to assist all key stakeholders.

For a vessel to enter naval classification all systems, equipment & components are required to be certified to the correct transverse requirements and standards as tailored for that project. No two projects can be assumed to be the same and hence it is highly likely that the certification requirements will also be different between projects. As indicated above, the certification processes and terminology also change over time.

Caution should be taken when discussing the certification required for product verification. The phrases “it should have a class certificate” or “type approved” in the authors experience have different meanings to different people and are often misquoted, leading to very expensive errors.

> *A compressor manufacturer was providing several compressor units on a new naval project. They were not certified by the classification society certifying the ship. Upon review of the material certification it was not possible to produce suitably verified and traceable records for the high pressure components. New compressors were ordered.*
>
> *A major component in the propulsion train was proposed to be manufactured at a works approved by the class society but with approval for a much smaller range of casting sizes. It was agreed that works approval could be upgraded following satisfactory destructive tests on the initial casting set. After many castings and six months delay, it became clear the facilities were not adequate and a new supplier was sought.*

The Tables I and II provides the full range of possible certificate types and levels of certification and indicate how they are used.

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Table I Class issued certificates

Class works approval

Certificate Type	Description	Example
Works Approval: Material and Qualification Procedures (MQS)	For material manufacturers only. Process to allow companies to manufacture materials for use on classed ships. It confirms that a manufacturer can deliver a product in terms of facilities qualified man power and process.	Steel, aluminium plate & sections. Steel, aluminium, & copper castings & forgings.

Class type approval

Certificate Type	Description	Example
Type Approval issued by class	Approval of product type for items of equipment & components, systems and welding consumables which comprises, as appropriate, Design Review and Type Testing and Production Quality Assurance. Confirms a product can be manufactured and performs against declared specifications and standards and conforms with class Rules and Test specifications.	Flexible hoses, Steering Gear, Welding consumables, Anchors, Software
Marine Equipment Directive issued by a notified body	Equipment approved under the European MED scheme with certificate issued by an authorised body. Can be part of a class type approval process.	SOLAS 1974: Life-saving appliances/navigation equipment/radio equipment MARPOL 1973: Marine pollution equipment, ODME, Separators, Emissions abatement COLREGS 1972: Lights signals

Product Certification

Certificate Type	Description	Example
Product Certification: **Sub-System**	Certification of system design which allow items to be placed on-board Classed vessels, which comprises the sub-system design approval. **Design Review –** Approval document The sub-system is installed and tested onboard under survey.	Fire Detection Networks, Fixed Fire Fighting systems
Product Certification: **Component Design Review and Certification**	Certification of a component which allows items to be placed on-board Classed vessels, which comprises: **Design Review –** Approval document **Type Testing** - Report **Manufactured under Class Survey-** Certificate	Most items of equipment & components
Product Certification: **Component Tested and Certified**	Certification of a component which allows items to be placed on-board Classed vessels, which has been designed against a recognised national standard and comprises of: **Type Testing** - Report **Manufactured under Class Survey-** Certificate	Pumps
Product Certification: **Component Type Approved**	Certification of a component which allows items to be placed on-board Classed vessels, which has been type approved against a recognised standard and comprises of: **Design Review –** Approval document (where applicable) **Type Approved** - Report **Manufactured under Class Survey** – Certificate	Gas Turbines Diesel Engines tec.
Quality Assurance Scheme for Machinery	Quality Assurance Schemes enables part or full certification of products by the manufacturer without Class witnessing product testing & inspection (Self-Certification). Certification will be issued by Class.	Some Engine components

Material Certification

Certificate Type	Description	Example
3.2 Material certification issued by Class	Materials certification issued by Class for materials made at an approved works, against Class Rules and/or recognised international standards	Steel or aluminium plate & sections, or casting & forgings EN 10204:2004
Quality Assurance Scheme for Materials	For material manufacturers only. Process to allow companies to manufacture materials for use on classed ships. It confirms that a manufacturer can deliver a product in terms of facilities qualified man power and process.	Steel, aluminium plate & sections. Steel, aluminium, & copper castings & forgings.

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Table II Other Certificates

Works Approval (Non Class)

Certificate Type	**Description**	**Example**
Works Approval:	Similar to above, but not a Class scheme. Class societies will each require their own works approval.	Steel, aluminium plate & sections. Steel, aluminium, & copper castings & forgings.

Type Approval (Non Class)

Certificate Type	**Description**	**Example**
Type Approval not issued by the classing society	Similar to above, but not issued by the classing society. Class societies may require own Type Approval particularly if design review to rules is required. Accepted on a case by case basis on Classed ships. Supplier, Designer, shipbuilder to seek approval for use.	Flexible hoses, Steering Gear, Welding consumables, Anchors, Software
Type Approval not issued by the classing society. EU Mutual Recognition	Generally, accepted on Classed ships. Though certification may not be always be appropriate for a naval ship. Supplier, Designer, shipbuilder to seek approval for use.	Refer to the EU MR website for details: https://www.euromr.org Only components and equipment that have a low safety criticality are eligible.
Marine Equipment Directive not issued by the classing society	Generally, accepted on Classed ships. Though certification may not be always be appropriate for a naval ship. Supplier, Designer, shipbuilder to seek approval for use.	SOLAS 1974: Life-saving appliances/navigation equipment/radio equipment MARPOL 1973: Marine pollution COLREGS 1972: Prevention of collisions

Product Certification (Non class)

Certificate Type	**Description**	**Example**
Product Certification: **Sub-System**	Similar to above, but not using Rules of the classing society. Generally, not accepted on Classed ships. The Rules and standards can differ from other Classification Societies. Project requirements may differ.	Fire Detection Networks, Fixed Fire Fighting systems
Product Certification: **Component**	Similar to above, but not using Rules of the classing society. Generally, not accepted on Classed ships. The Rules and standards can differ from other Classification Societies. Project requirements will differ.	Most items of equipment & components
Manufacturers Certificate of Conformance	A manufacturers certificate issued for a system or component for design, test and manufacturer under their own Quality system. Normal to a recognised international standard. Can be used on classed ships where Rules allow. NOTE: The cases where they are allowed is very limited and small.	Motors under 100kW and other electrical equipment. Rules class III piping systems
Navy Approved Equipment	Equipment approved by the Navy through their own processes or schemes Can be accepted in a classed system if evidence is provided that it meets the project requirements and equivalent level of verification activity as required by Class.	Military and some government furnished equipment Class certified equipment may require further approvals for, smoke toxicity, shock.

Material Certification (Non Class)

Certificate Type	**Description**	**Example**
3.2 Material certification by authorised body	Material certification issued by an independent authorised body from the place of manufacture against a recognised international standard Generally, not accepted on Classed ships. The Rules and standards can differ from other Classification Societies. Works approval needs to be in place.	Steel or aluminium plate & sections, or casting & forgings to international standards EN 10204:2004
3.1 Material certification by manufacturer	Material certificate issued by the manufacture against a recognised international standard Can be used on classed ships where Rules allow.	Class III pipes and fittings EN 10204:2004

Development of an equipment certification strategy

It is essential that suppliers deliver equipment and components to the right specification and with the right certification. This can first be achieved by ensuring the requirements are clearly defined and understood from the start.

Figure I shows the flow down of requirements for certification which unsurprisingly, are similar to a systems engineering vee diagram. However, whilst design requirements often follow a controlled process of specification, design, test and verification; product verification requirements may not. Verification and acceptance may focus on the final delivered documentation and witnessed factory testing but not necessarily the integrity of the components, materials and the soundness of manufacturing processes. The classification process is focused on the integrity of the manufacturing process as demonstrated by the 1876 Rule requirements for a roof over the build facility. It is also focussed on the recording of objective quality evidence which verifies that necessary processes have been satisfactorily completed. Whilst a ship builder or manufacturers quality system will verify defined checkpoints are completed, classification survey supplements this with process reviews, historical performance, industry benchmarking, random checks and patrols.

A strategy has been developed with recent projects, observing what has worked to ensure correct product verification requirements are achieved and what has not.

- Early engagement is essential with the design and procurement teams which should continue right through build until final setting to work and commissioning.

- A pre-build project manager should be assigned who is responsible for developing supply chain requirements. On large and complex projects, a separate supply chain lead may be appointed. This is to ensure consistency and focus on the equipment certification issues.

- Early discussion on the procurement strategy is important, clear definition of rule requirements and class notations should be in all equipment technical specifications. Words used need to place the responsibility for correct certification on the Supplier but also provide opportunities for support and clarification.

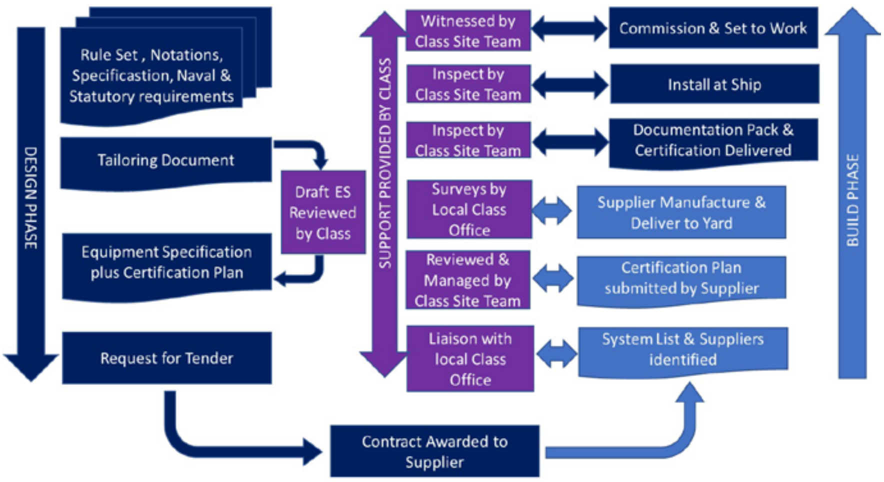
- Unambiguous statements on certification requirements should be avoided e.g. “Class certified COTS equipment“ as they may lead to many costly discussions after delivery of the equipment in the shipyard.

- Within the request for tender, a template for a certification plan can be included, this requires the suppliers to declare how they will meet the classification certification requirements. Experience has shown that this can work very well and force question to be asked early in the process and remove incorrect assumptions.

Once the equipment specifications and requests for tender are sent out, it his highly likely that the suppliers will then contact their local class society office to discuss the certification requirements. For complex projects, a connection needs to be made between the local office and the project office to ensure project requirements are understood.

Local offices must be able to answer any queries from a potential supplier with accuracy, confidence and consistency. Therefore, the project manager will issue a project work instruction that will introduce the project and provide all necessary information on notations, rule requirements including project specific technical requirements and transversals.

Figure I Equipment Certification process



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As suppliers are brought on contract the project manager will be building and managing a list of systems, associated equipment and suppliers. See table III. It should include certification requirements and track contact, progress to certification and installation. It should be regularly reviewed to make sure there is no incorrect or over specification of requirements which may drive in cost.

Table III System and equipment list – DIESO system

System ***Equipment***	***Category***	***Notations***	***Design Appraisal and testing***	***MATERIAL Verification/ certification***	***Equipment Verification/ Certification***
Ship's Fuel (DIESO) Class II Pd>7 bar	Mobility	+LMC Mobility CCS PSMR* RAS(ABV) EP	NSR + FMEA	-	-
DIESO Pumps	Mobility		Type Test	Class 3.2 cert	Product (test)
DIESO Filters	Mobility		NSR v2 p8 Ch 2	as per Rules	Product (App + test)
DIESO Centrifuge modules	Mobility		Centrifuge Type Test	Class 3.2 cert	Product (App + test) module
DIESO Valves	Mobility		none except resilient valve seat	Class 3.2 cert dia>50mm	Product (test) dia>50mm
DIESO Piping	Mobility		None	Class 3.2 cert dia>50mm	n/a
DIESO Couplings	Mobility		Type Test unless flanged	3.1 cert	Type Approval unless flanged
DIESO Sensors and Actuators	Mobility		none	3.1 cert	Manufacturers certification

Checking of certification is done once the equipment & components arrive in the yard. This is the best time for the local class site team to check the document pack for compliance. Too often the surveyors in the yard do not see any certification until a lot later. The later these checks are done, the more costly any required corrective action will be.

With the installation complete and certification verified. Shipyard setting to work, commissioning and final acceptance can be completed by the class surveyor.

Continuous concise and accurate communication between all stakeholders is essential if a project is to run smoothly. There are some key activities which can help:

- Early engagement with the design and procurement teams is essential this should include training on supply chain and certification requirements to be help inform on the impact of class in the supply chain. and the LR requirement for that project.

- Guidance documents can be developed to help define certification requirements that can be sent to suppliers to help and assist. These guidance documents can be focused to a project specific needs to address general bulk procurement packages or to target specific technical requirements.

- Include certification in wider supplier communications and events to raise awareness of the issues and feedback lessons learned.

Where requirements are not effectively communicated down the supply chain, costly rectification can result.

A lubricating oil purifier module fully compliant with the commercial and naval rules was supplied to a project. These modules on passenger ships are always fitted in dedicated purifying rooms. On the naval ship, they were fitted in the same space and the diesel generators categorised as high risk machinery spaces. The rules do not permit the use of a particular type of coupling used on the module in this space as they are not adequately fire rated. The couplings required removal and new pipes fitted. If the technical specification had specified, the installed location, then the non-compliant couplings may have been identified earlier.

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A particular type of bellows with Type Approval was fitted to a fuel oil piping system. Naval requirements for noise reduction and flexible mounts meant that a large number were fitted. When the Type Approval certification was reviewed after delivery, it was discovered that they did not have suitable fire test certification and had to be replaced. The markings on the product were not clearly described on the Type Approval certification so it was not immediately obvious which approval conditions applied to which product. In addition, for some of the products to pass the fire test they needed to have additional protective sleeves applied. Approval conditions on certificates need to be carefully examined.

Management of equipment certification needs to begin in the design stage. Long design periods mean that specified standards may be different at the time of manufacture and may not provide the integrity or design intent required. A standards management system which tracks change and assesses the impact can help, however it needs to be maintained through the build programme which could be up to 15 years. In certain cases, materials considered acceptable at the design stage may become prohibited, so the standards management system should consider future legislation.

Long build periods also mean that lifed item can go out of date before the ship is ready for delivery. Several projects have required replacement of flexible hoses and bellows delivered on equipment which to meet compartment close out dates, was procured and installed early. Procurement contracts should take account of this with later delivery for lifed item or replacement parts.

SUBMRINE PRODUCT VERIFICAION

The previous section of this paper has discussed how we can apply the risk based assurance regime inherent in the classification system to naval surface ships, the adaptions that need to be made and some of the challenges faced. Can we apply a similar system to a submarine and benefit from this established process? Submarines are expensive and complex naval assets; a well-managed supply chain is essential to provide product assurance and can increase submarine availability and reduce through life costs and give the navy greater platform availability.

The supply chain is key, but submarines have a smaller supply chain due to the uniqueness of their equipment and materials, this is simply down to fact there are less submarines compared to ships, so can submarines benefit from the surface ship supply chain and Classification assurance process?

There some are key differences between ships and submarines that need to be taken into account before discussing the issue of assurance and product verification.

- We do not have an established international common rule set or common requirements, each submarine is unique with its own set of assurance processes and quality requirements.
- The transverse requirements for a submarine and generally wider in scope and more restricting. It needs to be tougher, quieter and cope with more than a surface ship including an enclosed atmosphere.
- Submarines have space and weight challenges, compromises are required to achieve a viable design.
- Equipment will be required to operate in normal, abnormal and emergency conditions which places significant demand.
- Most importantly, the risk associated with failure of certain components is substantially higher (total loss of crew) so a higher level of integrity is required.

Categorisation

The surface ship categories, non-essential, essential, ancillary, ship type and mobility are useful and can be directly applied to submarine equipment. For example, provided transverse issues are dealt with, the level of product verification required for a submarine fuel transfer pump or separator, (which is not a single point of failure and which is indirectly supporting submarine propulsion) could be similar to that required for a surface ship. However, the level of product verification for a submarine hull valve

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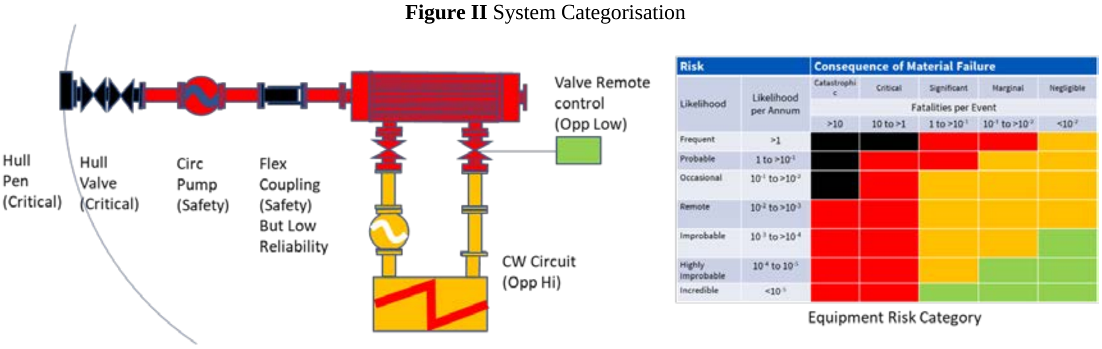
which could lead to an unrecoverable flood is going to be significantly higher than that required for a ships side valve, where the flooding can be managed and if not, there is a means of evacuation for the crew.

So, submarine product verification can be addressed by having an enhanced product verification category with some more stringent quality and integrity requirements.

For a submarine, the impact of a failure can be multi-faceted and there may be indirect safety consequences in addition to the direct issue. A careful examination of the consequences of a failure, loss of system function or loss of a compartment and their impact on the submarine must be considered when determining the product verification category. The category may also depend on the reliability of the component, less reliable equipment e.g. flexible bellows may require greater assurance.

In the example below, the product verification categories (Critical, Safety, Operational Hi, operational Low) decrease when inboard of the hull valve because of the isolation provided and an assumption that the level of flooding is such that the submarine can be recovered with an acceptable timeframe. This leads to a variety of product verification categories in the system. By comparison a surface ship would have one category based on system function, though product verification requirements for hull valves are increased in class rules to recognise their criticality. In figure II, categorisation of the inboard cooling water circuit may increase if the equipment it serves has a safety or critical function. Conversely, it may reduce if there is diversity and redundancy in the submarines systems.

Figure II System Categorisation



Transverse requirements

Submarine transverse requirements will be defined and whilst similar subjects are addressed e.g. temperature, vibration, EMC, shock, the number of requirements is greater as there are some submarine specific issues such as atmospheric pressure and toxicity to consider. The submarine has an enclosed atmosphere with limited opportunity for venting which means that heat, emissions and materials need to be tightly controlled. The military features whilst the same, will have more stringent criteria on a submarine, e.g. shock, noise. Furthermore, transverse requirements may be applied for design aspects, which if not controlled, may compromise the viability of the design, e.g. dimensional, weight and interface constraints.

Assurance levels

The certification processes used to deliver product verification in Tables I and II can be used for a submarine, but more work is required to define the product verification activity behind the certificate. It will be determined by the category and for the higher categories, standard assurance methods will not deliver the levels of integrity required.

However, for lower category requirements they may be suitable and classification requirements may offer a simpler and more effective way of specifying assurance requirements to the supply chain. For example, the marine equipment Type Approval process can be utilised using a suitable international standards, augmented by project transverse requirements. The materials certification process can be used for certification of castings forgings or plate against rules or national standards.

For the more complex equipment and higher categories, suitable baseline standards may not exist, or they may be insufficient. Therefore, the technical requirements in the equipment specifications will

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need to be more extensive and quality requirements defined. An inspection and test plan will need to be developed and agreed to define the product verification activities and level of scrutiny applied.

Table IV Systems and Equipment list

System / *Equipment*	*Category*	*Design Appraisal and testing*	*MATERIAL Verification/ certification*	*Equipment Verification/ Certification*
SW Cooling Class I/III	Class	Operating Description, Transverse Req. Calculations ASME + Pressure/flow Plan Review, FMECA,	-	-
Hull Valve	Critical Class I	Design Code Shock test Function testing	Class 3.2 cert +NDE	ITP Pressure testing (proof) Product (App + test)
SW Piping	Safety Class I	Design Code Shock Calculation	Class 3.2 cert	ITP Pressure testing Product (App + test)
SW Pumps	Safety Class I	Design Code Shock Calculation Noise test	Class 3.2 cert +NDE	ITP Pressure testing Product (App + test)
SW/FW Heat exchanger	Safety Class I	Design Code Shock Calculation	Class 3.2 cert +NDE	ITP Pressure testing Product (App + test)
FW Pumps	Operational Hi Class III	Type test Shock Calculation Noise test	3.1 cert	Product (test)
FW Piping	Operational Hi Class III	None	3.1 cert	none

Development of an assurance strategy

The same principles regarding early intervention, planning and education apply. However, the submarine product verification process is entirely bespoke and built up for each project. LR have a submarine assurance framework which provides a process and templates to manage and control these product verification requirements.

A dedicated supply chain product verification project manager is required to determine the scope of application, establish the design basis, co-ordinate with suppliers, review their ITPs and certification strategy to confirm the product verification activities. In a similar manner to surface ships, detailed work instructions are issued to guide surveyors.

The process is typically managed centrally rather than relying on the supplier and local office interactions. However, the same survey work force experienced in manufacturing processes is used and the same product verification techniques of patrol, witness, hold, review and audit are employed.

There are benefits of using the established naval ship surface product verification processes in the submarine supply chain. Manufacturers will typically supply surface and submarine projects and may welcome a common process. In some cases, classification society rules can be used for submarine materials or equipment, providing the transverse issues are taken into account and a suitable justification made for their use.

CONCLUSION

Adequate assurance of equipment and materials in the supply chain was recognised as an essential part of classification and can be seen in early versions of classification society rules. IMO statutory requirements have also required that product verification be undertaken to ensure the integrity of equipment supporting safety systems and protecting the environment. The EU have developed the Marine Equipment Directive to standardise the approval and certification of certain equipment within that scope. This results in a reasonably well understood and offer an effective system for assuring the quality and integrity of equipment on commercial ships.

With the application of these classification and statutory certification principles to naval surface ships, Navies and Naval ship builders have been able to benefit from this system and gain an almost

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automatic assurance of items in the supply chain within the selected scope of classification. The system has its limitations when applied to naval ships and enhanced processes have been required to: manage transverse requirements, implement tailoring of standards, identify the impact of class certification early, gather feedback on implementation, train and educate naval suppliers, designers and procurement teams. Over several projects several issues have been identified, equipment has been rejected, repairs made and suppliers changed. As a consequence, the authors have learned lessons and subsequently improved the rules plus the processes that support shipyards and suppliers.

We have demonstrated that the same principles, suitably enhanced, can benefit the naval submarine community. For less critical components, the naval surface ship process can be used as is, provided transverse requirements are included in equipment specifications. For more complex or critical equipment, bespoke technical design requirements and product verification requirements need to be developed. These will be determined based on a risk category derived for the equipment based on: immediate failure consequences, impact on submarine function, reliability and redundancy. Whilst requiring more management and central co-ordination it is still a relatively straight forward process and is being deployed on several submarine projects.

So, we have shown that the 260 year old product verification principles are still relevant and with a little modification, plus some good organisation, they can be used as an effective means of assuring quality in the supply chain, providing navies confidence in their key assets.

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