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Optimizing the Requirement Engineering Process: A Case Study of I/O List Management in Integrated Automation Systems

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Abstract. Integrated Automation Systems (IAS) suppliers in the maritime sector have been facing the cost pressure to deliver projects over the years, while the system complexity rapidly increases. How to improve the IAS delivery process to assert the project margins thus has become a critical issue. The IAS delivery process is mainly related to design and production activities of the software activities. For instance, the requirements documentation and Input/Output list (I/O list) management during the software design and engineering phases tend to be recurring reasons for delays in the IAS production. Thus, this paper focuses on how to optimize the requirements engineering (RE) process related to I/O list management in the IAS production. A real-life case study is conducted from both the customer (i.e. Shipyard) and supplier (i.e. *The case company*) perspectives to investigate I/O list management in the RE process of the IAS production. It is found that late design changes to the I/O list are the main reasons for delays in the IAS production; the lack of standardization, documentation, inconsistency between customer and supplier milestones as well as the I/O list ownership by customers are the important root causes. Based on the case data, the solution in resolving those root causes is derived for reduced man-hours in the RE process of the IAS production.

Introduction

Company. *The case company* (i.e. *The Company* in this paper) is a Europe based company which has been a technology driver in the maritime sector for many years. *The Company* is a well-known supplier of IAS and related equipments for the maritime industry. Over the last 10 years, it has become one of the largest suppliers of IAS for a special *branch* with over 180 deliveries in the Oil & Gas sector.

Background. The major Asian shipyards are the main customers of *The Company*'s IAS for its target vessels. These shipyards have, in the recent years, decreased activity due to the loss of investment in the oil industry (Ban, et al., 2016; Seoul, 2016; OGJ, 2017). The decreased activity reduced contract prices with *The Company*, as the demand of a lower price of the IAS. Under increased cost pressures, *The Company* has a need to optimize their current way of working.

Challenge. The system complexity rises while the time-to-market is getting more important due to the rapid evolvement within the IAS field (Vogel-Heuser, et al., 2017). A well-performing RE process is found to be crucial to keep up with the increased complexity of the IAS delivery (Vyatkin, 2013). There has been a strong initiative within *The Company* to improve the RE process in order to reduce the man-hours during an IAS delivery.

Software (SW) engineering has played a larger and more important role of the IAS delivery. The functional requirements for the IAS software are usually elicited from the I/O list, Functional Design Specification (FDS) and Piping & Instrumentation Diagrams (P&IDs). These three documents constitute the governing functional requirement specification and are linked together through tags. The tags describe the input/output signals of the IAS and are documented in the I/O list, FDS and P&IDs. Inconsistency between these tags often leads to design flaws that are costly to resolve (Jetley, et al., 2013). Prior to the software production, the I/O list, FDS and P&IDs need to be verified through iterations to ensure that these documents are consistent. Changes to these documents during IAS-SW production will cause new iterations of the requirements documents have to be initiated and that the implemented SW has to be updated according to the revised requirements documentation. In order to prevent that changes to these documents are made during the IAS-SW production, *The Company* and the shipyard have agreed that changes after a certain date (design freeze) will have a cost-impact for the side that is performing the change. In the case of IAS, the design freeze is usually 10 weeks before the SW Factory Acceptance Test (FAT).

The current RE process allows to elicit requirements and verify requirements documentation of the I/O list through iterations, however it does not seem to work very well. The iterative design processes tend to bypass design freeze and be close to the SW Factory Acceptance Test (FAT) date, which results in major workloads for the project team and rapid accumulation of man-hours just before the SW FAT. It has been pointed out that the I/O list usually does not reach the desired quality until close to SW FAT. The current I/O list management is thus seen as a bottleneck among the I/O list, FDS and P&IDs that postpones the IAS-SW production.

The IAS Case. The IAS deliveries in the case study varies from 12-18 months and up to 24-30 months. An IAS delivery starts with a kick-off meeting with the shipyard, where both sides get to greet each other face to face and settle the scope of delivery. The IAS deliveries include both a hardware (HW) and SW scope. The design and procurement phase of the HW starts immediately after the kick-off and the HW is finally tested through a FAT with the shipyard and class societies. The SW design and engineering phase starts just before the HW FAT. While the HW consists of physical elements like operator stations, consoles, field stations, controllers and I/O modules, the SW contains logical instructions that performs a specific action like opening a valve or starting a motor (see Figure 1). The logical instructions are made according to the functional requirements described in the FDS and most of their behaviors can be pre-defined in Functional Blocks (FB) based on readings of the inputs. The results from the FB algorithm for instance can be events or measurements (Lewis, 2008). The FB typically has interfaces for internal communication towards the physical I/O module that mainly interacts with devices like motors, actuators and sensors (see Figure 2). To give an example, solenoid actuators can have I/Os allocated, like Energize (output from IAS) and feedback from the equipment controlled by the actuator, like an open signal from a valve (input to IAS).

The specifications of the interfaced I/O signals are stored in an I/O list, which is the governing document of equipment to be interfaced. The I/O list will ensure that the desired functionality described in P&IDs and FDS can be realized by means of the available physical signals; a valve cannot be opened from IAS without any signal dedicated for that specific valve. When the I/O specifications are known for a certain system, the I/O list is imported to a SW builder tool that automatically connects the physical channels on the I/O module to the related FB field interface and further creates system files with a functional SW (see Figure 3). The I/O point and FB will be automatically parameterized with the available data that exists in the I/O list (see Figure 4). By using pre-defined clusters of FBs that form sub-systems like ballast control, the related I/Os can be automatically mapped to the clusters field interfaces instead of single FBs, but this requires a minimum amount of data specified in the I/O list.

This means that the majority of the software can be deployed automatically with the desired functionality if the I/O list contains the necessary data for the related system. It has been experienced by *The Company* that eliciting the necessary requirements from the I/O list in the RE process is a challenge to perform in due time to design freeze. As the IAS interfaces several thousands hardwired signals, it is critical to ensure an engineering process with correct requirements throughout the design phase in order to prevent major changes to the I/O list in the IAS-SW production. Otherwise, the changes to the I/O list after design freeze will delay an IAS-SW production and an IAS delivery.

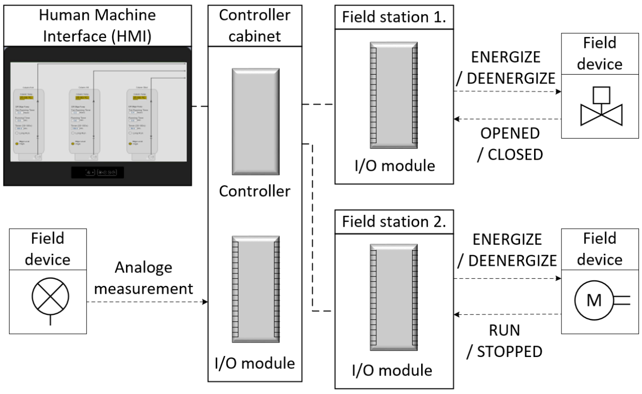

Figure 1. Simplified IAS Layout

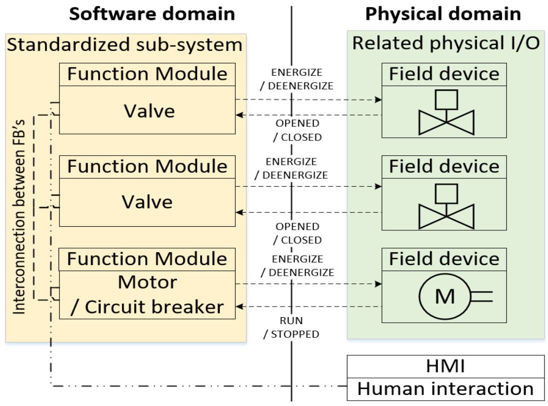

Figure 2. Domain Interaction

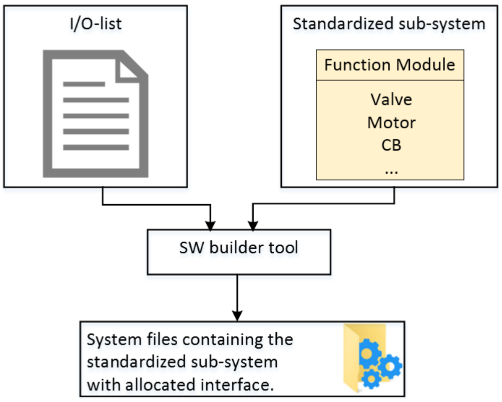

Figure 3. IAS-SW Production

I/O tag	Unique name ID that specific I/O
Data type	Analoge Input/Output Digital Input/Output
Signal type	Current, Volt, N.O (Normally Open), N.C (Normally Closed), RTD (Resistance Thermometer)
Alarm limits	Triggers an event if the reading is below/above threshold
Power	External/Internal loop power
No. of wires	Number of physical wires related to that specific I/O
Controller ID	Unique ID of controller that specific I/O is to be interfaced
Termination details	Name of I/O module and I/O Channel that specific I/O is to be connected
Card type	Name of I/O module type

Figure 4. Example of I/O Signal Specifications in I/O list

Problem Statement. To address the challenges of late design changes during IAS-SW production, this research is to optimize the current RE processes through I/O list management for man-hour reduction. There is an explicit need to answer the following questions:

- What are the causes related to the I/O list management delaying the software production?
- How to resolve the causes related to the I/O list management for an optimized RE process?

Knowledge Applied

In order to investigate what causes the delayed system production, this paper adopts the Systems Engineering (SE) approach as the backbone of the research. A system can be defined as: "a number of elements in interaction" (Bertalanffy, 1968), which is the IAS in our case. The fundamentals of SE approach in resolving the system problem is to understand the stakeholder needs, explore opportunities, document requirements and synthesize, verify, validate and evolve solutions while having a holistic view on the system (SEBoK, 2017). In response to system-related challenges, it usually starts with how to develop requirements at both stakeholder and system levels, which is known as RE process (Sols, 2014; Sommerville, 2016). A clear scope up front, reviews, and stakeholders involvement are found as success factors to improve the RE process (Niazi & Shastry, 2003). The RE process is usually managed and affected by the stakeholders and the RE method (Sharp, et al., 1999). According to Freeman (1984), "a stakeholder in an organisation is any group or individual who can affect or is affected by the achievement of the organisation's objectives". With an identified list of the stakeholders, the relevant stakeholders can be involved in the root-cause analysis for the delayed SW production in the IAS case. The root-cause analysis provides evidence in order to understand the 'as-is' situation of the RE process. The root-cause analysis conducted in this paper is based on techniques that are commonly used in the field of SE. Specifically, the focus group ensures that individuals can share each other's experiences and points of view, which enables clarifications and explorations in ways that would be less easily accessible in a one to one interview (Kitzinger, 1995). The benefits of conducting a focus group is to effectively gain stakeholders involvement, which is important throughout a RE process (SEBoK, 2017). The data collected from the focus group in combination with individual interviews with stakeholders is believed to provide a better understanding of the root causes related to the RE process.

The root causes regarding the RE process are related to the level of a company's RE maturity. Sommerville and Ransom (2005) proposed three different levels of RE maturity which is based on the three first levels in the Software Engineering Institute (SEI) Capability Maturity Model: Initial, Repeatable and Defined. Similar to the CMM (Paulk, 1995), *The Company* is ISO9001 certified, and it is therefore reasonable to consider its internal procedures of the company as "Defined" (Sommerville & Ransom, 2005). For any internal competence development, the most frequent solution is to improve procedures like engineering manuals and how-to's, which has a strong relationship to the increased use of tools in *The Company*. Similar findings are found by Beecham, et al., (2003) in their empirical analysis of SPI problems in twelve software companies. Their main findings are that project problems, such as quality, timescales and technology, are directly linked to the low RE maturity companies, while organizational problems are associated with the high RE maturity companies. They also pointed that developers were most concerned about requirements, communication, tools and technology, documentation and testing, while project managers were concerned with budgets and estimates, timescales and change-management. In this regard, *The Company* has implemented the continuous improvement process (CIP) by periodically conducting A3 process solving technique (Sobek & Jimmerson, 2004) for addressing internal challenges. The CIP meeting are part of *The Company's* lessons learned process, running in the end of each project phase. The analyses of CIP minutes related the IAS case can help the challenges identification related to the maturity of the internal RE process.

In our case, the optimization of internal RE process is not only related to how requirements regarding the I/O list are elicited, derived and validated but further standardized and documented. A standardized system is found to be beneficial rather than putting effort into short-sighted strategies that will compete for the available recourses (Bass, et al., 1999). There will, though, be a number of risk factors related to implementing such practices related to organizational culture, organizational structure, the market to which the process model is applicable and employees' experience and expertise. If the organization is able to reuse its current solutions, this will have many advantages, as the software development becomes more efficient while the product reliability will be increased and maintenance requirements will be significantly reduced (Crnkovic & Larsson, 2000; Sommerville, 2016). Developing standardized solutions rather than a single system will reduce the development costs and shorten the time to market. Moreover, the level of granularity is an important factor for successful reuse (Maga, et al., 2011). Thus, the requirements related to the I/O list have to be standardized based on the existing sub-systems (Sommerville, 2016). In order to standardize the I/O list, the principle of having the I/O list interfaces through both black-box and white-box views (SEBoK, 2017) is applied in this case. In addition, the importance of requirements documentation has been highlighted in the software development process (Dubey, 2011), i.e. the I/O list, prior to the SW production for IAS in this case.

Data and Methods

The paper employs case study method to investigate why delayed IAS-SW production exists regarding I/O list management and how the related RE process can be optimized. The methodical and source triangulation methods in "Case study research in software engineering" (Runeson, et al., 2012) are used to increase the precision and strengthen the validity of the research data. Only the IAS projects that completed the SW FAT within the recent 3 years are considered in the case study in order to include the latest technology. In total, there are 5 IAS projects selected in the case study with sufficient data related to stakeholders. The performance of the RE process optimization in the case study are measured in terms of man-hours reduction of the case projects.

In line with the SE problem solving approach, the methodic process is shown in Figure 5. The problem statement was derived from the need of the man-hours reduction within the related department in *The Company.* After validation of the defined problem statement, the related stakeholders were identified. The stakeholder analysis is conducted which determines their roles in the IAS cases. Further, a root cause analysis was executed for seeking the root causes related to the I/O list management which delay the software production. Through the root cause analysis, 8 root causes were identified and then used to gain a holistic view of the 'as-is' situation of the current RE process. A visual illustration was made of the 'as-is' RE process for the shipyards and *The Company,* and mapped towards the IAS milestones. Based on the 'as-is' situation, areas for improvement were obtained and then used in order to derive a solution. During the case study, the I/O lists for the IAS case studies were compared in order to enable standardization of the 'as-is' RE process. The derived solution was finally verified through a survey and expert review, and then validated through deployment in an ongoing IAS delivery. The details of key steps are elaborated below.

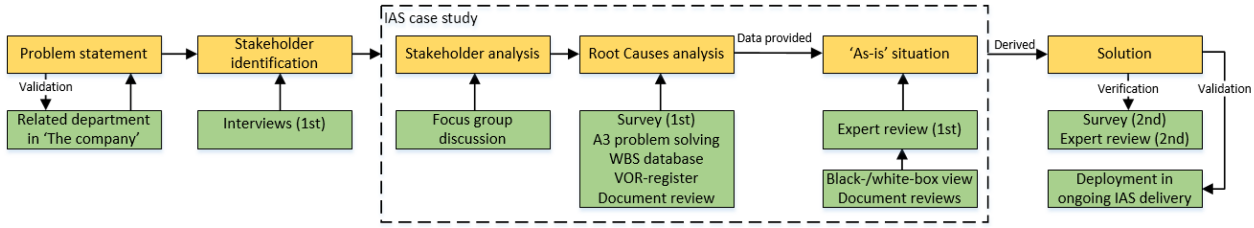

Figure 5. Research Methodology

Stakeholder Identification. To identify the IAS stakeholders and to get an understanding of how the IAS stakeholders experience the I/O list management, one to one interviews were conducted. The interviews were organized as semi-structured interviews with a mix of open and closed questions. The interviewees were two lead engineers that together have over 30 years of experience within the IAS project execution. They have a holistic view of whole the IAS life-cycle process due to their ample experiences, and have mainly been involved in communication towards stakeholders, system standardization and development work over the past three past years, which are fit with this research. The identified list of the relevant stakeholders was used in the stakeholder analysis.

Stakeholder Analysis. Stakeholder analysis was conducted through a focus group discussion. The focus group consisted of three lead, two senior and two junior project engineers. The participants had a mixed background within the field of IAS, which enabled holistic view of the identified stakeholder's role in the IAS case. The stakeholder analysis provided explicit inputs to the root cause analysis in terms of which stakeholders that had to be involved.

Root Cause Analysis. A survey was conducted in order to understand why late changes to the I/O list occur and pinpoint the weaknesses of the current IAS RE process for both the customer (i.e. shipyards) and the supplier (i.e. *The Company).* The shipyards in this case study are based in Asia. The cultural gap and the far distance between *The Company* and the shipyards included in the IAS case study make it more difficult to communicate and to understand each other intentions (Ferris, 2007). A survey was therefore a suitable method to collect data; the survey had tick-off boxes in order to eliminate user errors and ease the work of analyzing and compare data between *The Company* and the shipyards. The attendances had to answer 35 Likert scale (Allen & Seaman, 2007) and Yes/No questions. In the survey, a time line was presented, and the system responsible at *The Company* and at the shipyard were to define a number of occurrences, e.g. when I/O list related work was started and completed of milestones and challenges. The data collected through the survey were generalized and used to map the current RE process for the IAS case.

In addition, the analysis of the A3 problem-solving (CIP) meeting minutes are conducted for specific challenges in the past IAS cases deliveries. The used hours related to I/O list management and SW production were extracted from the Work Breakdown Structure (WBS) for the IAS case deliveries. The hours were analyzed in order to check if the man-hours related to I/O list management were used after design freeze. The findings were used to prove that changes to the I/O list delayed the IAS-SW production and to provide inputs in order to map the project milestones. Further, the Variation Order Requests (VOR) for the IAS case deliveries were analyzed in order to prove that changes to the I/O list after design freeze caused an increased cost for the shipyard. The IAS delivery milestones were mapped by doing document reviews of the project plan for the IAS case deliveries. By comparing the IAS milestones with data provided from the survey, the inconsistency in the milestones between *The Company* and the shipyards was discovered and further analyzed.

'As-is' Situation. The root cause analysis was used to perceive the 'as-is' situation of the RE process from both *The Company* and the shipyards perspectives in the I/O list management for the IAS cases. A graphical illustration of the 'as-is' RE process and IAS milestones was made to enable a holistic view of the 'as-is' RE process. The 'as-is' analysis showed that by changing the ownership of the I/O list management process from the shipyards to *The Company*, the RE process could be optimized by starting the I/O list iteration at an earlier stage. In order to enable for an early iteration of the I/O list, the interfaces described in the I/O list had to be standardized towards *The Company's* IAS sub-systems. The I/O list was then standardized by comparing the I/O signal interfaces of the IAS delivery projects against the standardized IAS sub-systems through a "black- / white-box" view and requirements document review of the related FDS. To ensure that the intended functionality of the IAS sub-system was maintained, the standardized I/O list was further verified by the two lead engineers that participated in the stakeholder identification.

By utilizing the standardized I/O list, an optimized process for I/O list management can be derived. The solution was verified through surveys for *The Company* and the shipyards and internal IAS experts review by the two lead engineers that were interviewed for the stakeholder identification. The solution was further validated through deployment in an ongoing IAS delivery.

Case Analysis and Findings

To provide a holistic view is an important 'corner-stone' throughout the SE problem solving approach. It was therefore important to identify all relevant stakeholders and capture their views of the RE process. A stakeholder identification process was performed to list the stakeholders that had an interaction with the I/O list management process of the IAS cases deliveries (see Table 1).

Table 1. Identified Stakeholders

Baseline	Who	Interaction
Users	End-customer (Ship owner/operators)	Contractual, Fault tracing, signal overview
	Service Engineer (*The Company*)	Fault tracing, signal overview, corrections
	Commissioning Engineer (*The Company*)	Loop testing, system check
	Shipyard Commissioning Engineer	Loop testing, checklist
Developers	Project Engineer (*The Company*)	Main user. I/O list management, System design and implementation
	Lead Engineer (*The Company*)	Domain experts, System verification
	Project Manager (*The Company*)	Contractual
Legislators	Class-society	System approval
Decision-makers	Sales personal (*The Company*)	Quotation and selling to proposed solution
	Department manager (T*he Company*)	Recourses and approval of proposed solution
Customer	Shipyard Design Team	Main user. I/O list management, System design
	3rd part sub-vendors (satellite stakeholder)	Provides requirements of signals characteristics & amount of signals

Based on the focus group discussions, it was concluded that the baseline stakeholders were sufficient for the scope of research, and there was no need for further exploration of the satellite stakeholders (Sharp, et al., 1999). Further, each of the stakeholders' relationship and impact on the problem statement were discussed in order to select the relevant few. The lead, sales and project engineers from *The Company* are identified to be included in the case study as they were the stakeholders that had most information and impact of the current RE process related to the I/O list management. Moreover, the shipyerd design team need to be included as they are the direct counterpart of the RE process, and indirectly involved with the class society and 3rd party vendor's relationship on the I/O list management process.

Root Cause Analysis

To find the root-causes of how the current RE process related to the I/O list management is causing late design changes and software production delay, several analyses were conducted.

Internal Requirements Engineering Process Maturity. Sommerville and Ransom (2005) and Beecham, et., al (2003) pointed the RE process maturity level affects the RE process performance. In order to explore this further, the CIP meeting minutes related to the IAS cases were analyzed. There existed 23 CIP cases related to the IAS case deliveries. In total, 8 out of the 23 CIP analyses conducted can be related to the IAS-SW production process and I/O list management. For these cases, lack of competence (19%), lack of standardization (16%) and poor documentation (16%) were the most frequent root cases while the corresponding mitigation strategies were improvement of procedures/documentation (35%), increasing the focus on standardization (22%) and increasing the focus on front-end engineering (17%). This analysis shows that the internal RE process has a high need for improvement of internal procedures and standardization, which is related to the RE maturity. The internal engineering procedures need to be easily understand and follow for engineers that have not implemented the respective system before. Thus, the root cause 1 is found as below:

- The lack of competence, standardization and documentation related to the I/O list mangement affects the RE process performance in a negative way.

The Company's IAS engineer needs to have a high competence of how to manage the requirements documentation like the P&I, FDS and I/O list to ensure that they are consistent. The fact that the shipyards initiate these documents at different times, and make changes to requirements stated in the documents at different times makes I/O list management complicated for *The Company*. Dubey (2011) pointed that requirements gathering and design often seems blurred in the automation application development process and the primary reason is that requirements are detailed as the number of I/O and its specification has to be extracted from P&IDs and other design documentation. This is in line with the difficulties to elicit the needed requirements through the RE process in this case study. The survey shows that both *The Company* and the shipyards used too much time on the I/O list management. It is specifically related to the requirement inconsistency created between the I/O list and the FDS, as the shipyard has to wait for documentation related to its sub-vendors in order to elicit the correct requirements for the I/O list. This increases the RE process complexity and thus requires more man-hours and greater knowledge of the IAS engineer in order to have control of the inconsistent requirements. Thus, the root cause 2 is found as below:

- Inconsistency in requirements documentation increases the competence needed of I/O list management related activities, which causes increased use of man-hours.

An increased use of man-hours due the challenges regarding the RE process posit a need to find out if the increased use of man-hours is related to the delay of IAS-SW production. The reported hours were therefore analyzed and compared (see Figure 6) for the IAS case deliveries. Due to the different project schedule of the deliveries, the HW FAT, Design Freeze and SW FAT milestones were used as reference points, as the timeframes between these 3 milestones are quite similar. The avarage timeframe of the deliveries conducted in the case study os 22 months from project start until two weeks after SW FAT, while the IAS-SW production phase is defined between design freeze and SW FAT. The two weeks after SW FAT were included in the calculations by taking hours related to corrections of FAT punches into account. The hours analysis showed late changes to the I/O list caused an increased use of man-hours, in addition to the lack of documentation.

Hours Analysis of the IAS Case Deliveries. In the IAS-SW production phase, 60% of the accumulated hours was used on SW engineering activities while 13% was used on I/O engineering actvities. The other 27% consisted of HW engineering, documentation and project management acivities. The first I/O list submission from *The Company* to Yard is submitted 10 weeks before the design freeze, thus a dig in the time spent on I/O engineering (see Figure 6). In the IAS-SW production phase, the design phase iterations should be finished, but 34% of the total I/O list engineering activites occurred in the IAS-SW production phase, which proves that major changes are still occuring. It is reasonable to state that changes to the I/O list after design freeeze increase the hours used on software implementation and changes to requirements as changes to the I/Os characteristcs require an update of I/O blocks, function block interfaces and removal or implementation of functionality in the implemented software. Sommerville (2016) pointed a change to requirements usually means that the system design and implementation also have to be changed, and then retested. This matches the findings in the conducted survey, as the most time consuming work related to the I/O list for the IAS vendor was modification and corrections to the I/O list after design freeze. Thus, the root cause 3 is found as below:

- Late changes cause additional work after design freeze and thus increased use of man-hours.

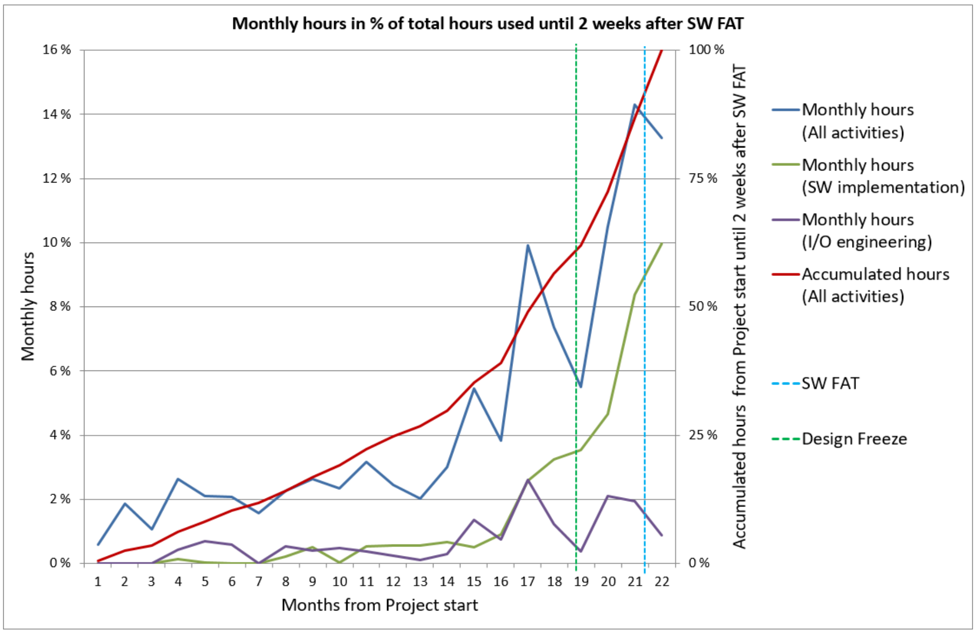

Figure 6. Hours Analysis

In order to mitigate the risk of changes to the requirements documentation, both *The Company* and the shipyard have agreed on a design freeze date that states the "deadline" for requirements documentation iterations. The design freeze date is set during the kick-off meeting were both *The Company* and the shipyard participates. During the HW FAT and SW FAT, it shall be verified that the governing rules and system requirements are reflecting the requirements documentation by both the shipyard and respective class society. At the Customer Acceptance Test (CAT), the IAS system functionality is being validated by both the shipyard and end-customer (typically ship-owner). The system requirements are verified through I/O list and IAS design documentation iterations between the shipyard and *The Company*, and the 1st revision of the I/O list is received by *The Company* before the HW FAT as an overview of the I/O modules is needed. Any change to the I/O list after design freeze has an impact on the HW scope of delivery, as changes to the number or specifications related to I/Os affect I/O modules. The amount of I/O modules depends on the number of signals to be interfaced, and this information tends to be somewhat incorrect. The variation order request's (VOR) for the IAS cases were analyzed, which showed 24% of the accepted and pending VORs was related to changes in interfaces and/or specified I/Os. Thus, the root cause 4 is found as below:

- Changes to the I/O list after design freeze lead to increased cost for the shipyard.

Lack of Consistency in Milestone Documentation. As the discovered changes to the I/O list appear after design freeze, late changes to requirements documentation affect the project performance in terms of increased engineering effort (Dubey, 2011; Sommerville, 2016). In order to explore the root causes of the late design changes, the milestone documentation was analyzed for the IAS case study deliveries. Currently, the shipyard has the ownership of the I/O list. To further understand why the I/O list is received late in the process, it is necessary to understand both *The Company* and shipyard project milestones. In typical shipbuilding industry project schedules, the main milestones are Contract Signing (C/S), Steel Cutting (S/C), Keel Laying (K/L), Launching (L/C), Sea Trail (S/T) and delivery (D/L). At S/C, the fabrication of the various ship modules is started and thereafter outfitted and painted. The hull erection is being built after K/L and outfitted with the belonging equipment as the hull is being built throughout the L/C. During the launching period, the IAS commissioning starts, field termination work is carried out by the shipyard and loop tested according to the I/O list. In Figure 7, the shipyard milestones are mapped towards *The Company's* milestones by doing a review of the various project plans for each of the case-study deliveries.

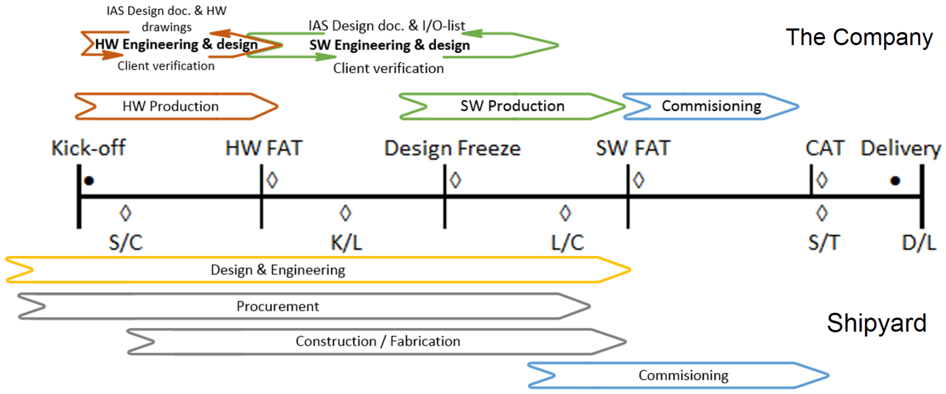

Figure 7. Milestones

The fact that the procurement period goes past *The Company's* design freeze period and the shipyard actually does not need the complete I/O list before the procurement phase is finished affects *The Company's* ability to elicit the necessary requirements from the I/O list in due time to the IAS-SW production phase. Thus, the root cause 5 is found as below:

- The lack of ownership by *The Company* in the I/O list management process causes late iteration of the I/O list.

Taking he late initiation of system integration activities at the shipyard into account can cause the shipyard to issue an incomplete I/O list. The survey shows that most shipyards reuse their I/O lists, but different engineers for the various projects are doing things in different ways, which attributes to non-consistency in the I/O list management process. Thus, the root cause 6 is found as below:

- The lack of a standardized way to manage the I/O list for the shipyards and *The Company* leads to increased hours on communication and a less effective and inconsistent way of working.

Different Perceptions of the I/O List Management Process. In the survey, *The Company* and the various shipyards were asked to define their perceptions of the I/O list management process (see Figure 8). In the past, the draft I/O list is usually received close up to HW FAT by *The Company*, but rarely ready for any constructive feedback from *The Company*. There are major differences in the expectation of when the I/O list should be finished. According to the survey, the shipyards experienced that system integration activities were the most time-consuming activities related to I/O list engineering, and if combined with the late response from their sub-suppliers, it would be very difficult for the design team to actually manage the design freeze, but the SW is still desired to be finished to SW FAT. From *The Company* perspective, the I/O list has to be finished before design freeze to be able to start the IAS-SW production in time and prevent late changes. Furthermore, it is found that both *The Company* and the shipyard would end up using too much time I/O list management. Thus, the root cause 7 is found as below:

- The huge gap between the expected periods of I/O list to be finished by *The Company* and the shipyard causes extra time of both on I/O list engineering between design freeze and SW FAT.

It has been proved that changes to the I/O list were performed after design freeze and close to SW FAT. This aligns with Figure 8 that The Company and the shipyard have different perceptions of when the I/O list has to be finished. Figure 7 shows that the procurement, design and engineering phases are stretching past design freeze, which implies that the sub-vendors of the shipyards may not yet have their interfaces fixed, which can indirectly cause new changes to requirements after the freeze date. It is also supported by the survey results that late responses from the shipyards sub-vendors are one of the major causes of delay to the I/O list together with changes to functional requirements. Thus, the root cause 8 is found as below:

- The delayed I/O list occurs as the shipyard currently has to wait for information from sub-vendors.

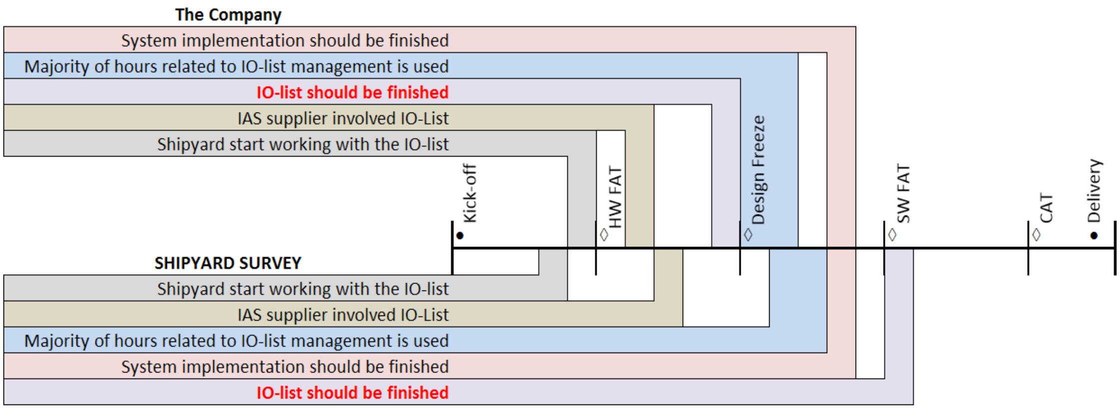

Figure 8. Different Perceptions in I/O List Management

'As is' situation

In the existing RE process (see Figure 9), the shipyard starts eliciting business and user requirements for the IAS system before the project kick-off, these requirements are specified in a Request For Quotation (RFQ). *The Company's* sales team uses the RFQ as the basis for the quotation which contains the amount of I/O modules and specification of I/Os to be interfaced. When the quotation has been signed by the shipyard, *The Company's* project team reviews the requirements documentation (FDS, P&IDs, I/O list) received from the shipyard together with the quotation received from *The Company's* sales representative in order to validate that the intended purpose of the IAS system can be achieved. *The Company's* project team translates the received requirements documentation into IAS design documentation and identifies the changes to the I/O list if needed. The iterative process of reviewing requirement documentation, including the I/O list, is to be finished until the design freeze, but according to the conducted projects, it usually lasts up the SW FAT.

So, what could be the solution for resolving the delay of software production of IAS? The excessive man-hours on eliciting, documenting and verifying new requirements for late changes to the requirements documentation, can be reduced by making the RE process consistent through a standardized way of working. In the current RE process, *The Company* does not have any ownership of the I/O list management in the RE process controlled by the shipyard. The shipyard's RE process takes time due to the inconsistency between the shipyard and *The Company* schedules, which causes the IAS SW engineering and design phase to go in parallel with the IAS-SW production. Under the current ownership, the RE process controlled by *The Company* is still dependent on the shipyards as they need to review the requirements documentation against the 3rd party requirements which aren't settled until after the design freeze. But in fact, the software production by *The Company* is not related to the 3rd party. The shipyard cannot complete the I/O list before close to SW FAT, as they are doing detail design and engineering that generate new requirements. Thus, a quality and efficient I/O list need to be initiated and created with a base of technical knowledge, which is *The Company* in the IAS case. Besides the ownership, the lack of supporting documentation and standardization related to the I/O list management process will also have an impact on the RE process, as the current work carried out is based on experience of different individuals in different projects, which again causes inconsistency for every IAS delivery. In order to gain more ownership of the RE process, I/O list should be standardized according to the IAS sub-systems by *The Company*. This ensures *The Company* to be able to initiate the I/O list iteration at an earlier point, which enables ending the IAS SW engineering and design phase before the IAS SW production starts.

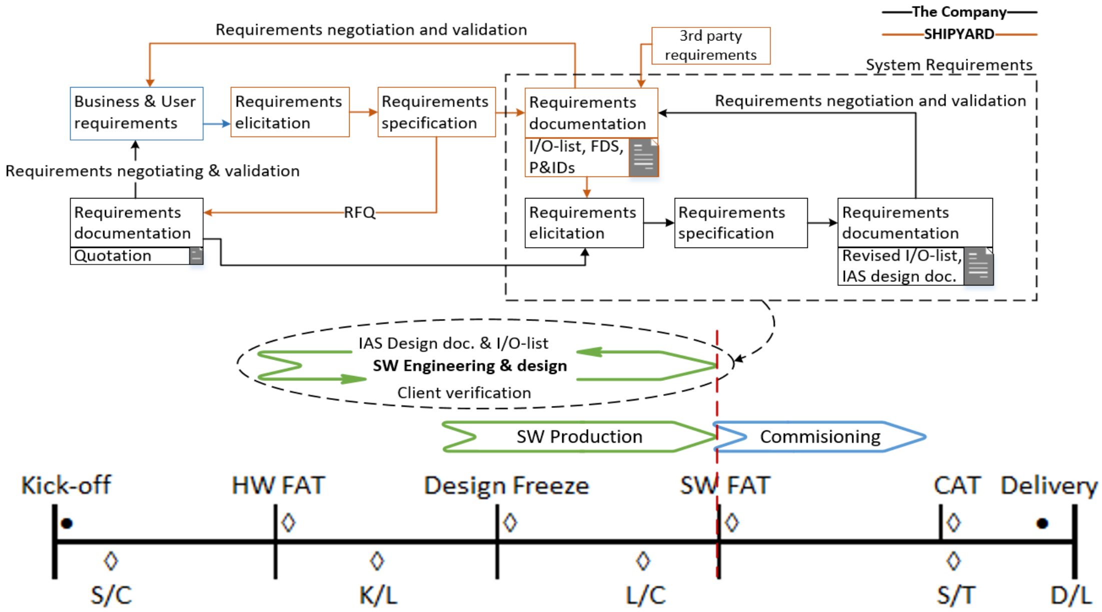

Figure 9. Current Requirements Engineering Process

Standardization of I/O list. The I/O list for the IAS case deliveries was compared and merged in order to create a I/O list that contained all the I/O signals provided from the various shipyards (see Figure 10). After the duplicate signals were removed, they were further systemized according to the belonging sub-system. A black-box view was then applied to allocate the signal interfaces to the related FB (see Figure 2). Through a white-box view, the signal interfaces that were needed in order to serve the purpose of the sub-system were mapped and further verified by domain experts and towards the FDS to ensure consistency. The signals were further allocated to I/O modules that were segregated according to governing rules and regulations.

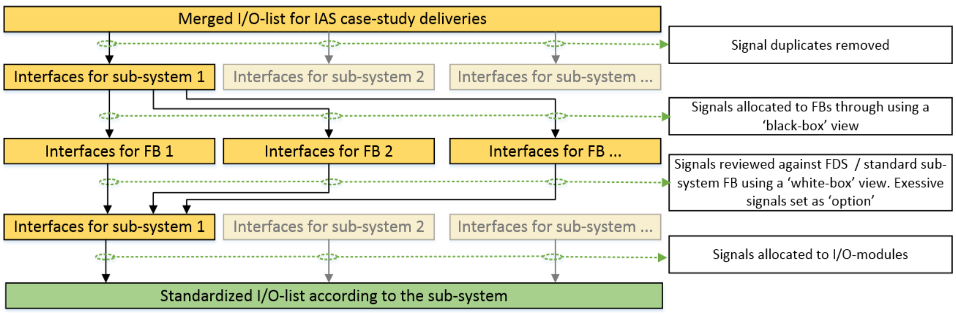

Figure 10. Creating a Standardized I/O List

In Figure 11, an example of I/O signals for a generator breaker of the Power Management System (PMS) is shown for both the merged I/O list and standardized I/O list. The numbers of Input/Output (I/O) signals to be purchased are usually specified in the contract. In the IAS case, the former prediction of I/O modules is generating VORs as the I/O list was based on the requirement specification provided by the shipyard. By using the standardized I/O list, the number of I/Os and I/O module type to be sold can be much more accurate as it will be based on the standardized sub-system made by *The Company* described in the IAS case.

Based on the case study, the following areas to improve were summarized from the 'as-is' requirements engineering process:

- The shipyards' ownership of the I/O list management process is currently causing late initiation of the I/O list iterations.
- The lack of knowledge and standardization of the current RE process causes inconsistency in the requirements documentation.

- It is proven that major changes to the I/O list that occur after the design freeze, consequently causes additional SW engineering.
- The most time-consuming work related to the I/O list for the IAS vendor is modification and corrections to the I/O list after the design freeze.
- There is an urgent need of improvement of internal procedures and system standardization, as the lack of proper internal procedures causes increased use of engineering hours.

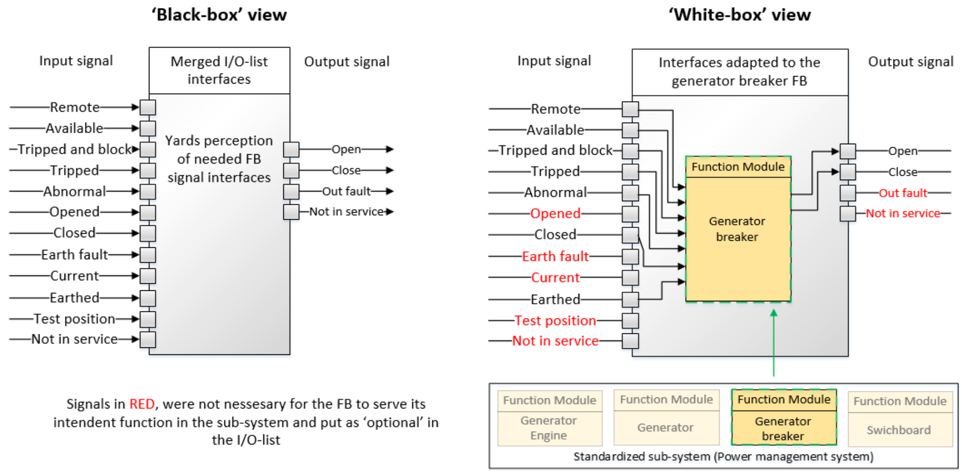

Figure 11. Merged/Standardized I/O list - Generator Breaker Example

Solution

Based on improvement areas analysis and the case study data, a solution was derived. By taking over the ownership of the I/O list management, *The Company* is not dependent on the shipyard to initiate the I/O list iteration. The standardized I/O list contains all the related interface signals that are necessary for the IAS sub-systems, which allows starting the iteration of requirements documentation like the I/O list just after kick-off. This enables *The Company* to be the initiator of the requirements documentation iterations. The shipyard receives the I/O list and IAS design documentation of the quoted systems for their review shortly after kick-off, which allows earlier implementation of sub-systems through the SW builder tool. The risk of inconsistency in the requirements documentation can be reduced, as it is already ensured that the I/O list is according to the FDS, and the shipyard would therefore have more time to ensure that the I/O list and FDS are matching the P&IDs. By providing a manual of the RE process, the lack of documentation is mitigated, and the required knowledge needed to design and implement a SW system is also reduced (Maga, et al., 2011). This means that *The Company* are able to take more ownership of the I/O list in order to expedite the I/O list iterations.

In the new RE process (see Figure 12), the standardized I/O list is now issued to *The Company's* sales engineers in order to improve their accuracy in term of determining the number of I/O modules and signals to be included in the quotation. By utilizing the standardized I/O list early in the RE process, the iteration of I/O lists and IAS design documentation is initiated by *The Company*, and provided to the shipyard after kick-off. This will provoke an early system validation process for the RE process controlled by the shipyard, and improve the requirements information gathering process of the system interfaces in *The Company's* SW engineering and design phase.

Increased standardization and change in ownership of the I/O list management process is feasible, especially when *The Company* is the knowledge owner of how to create and produce the IAS SW according to the I/O list. In addition, the SW production of sub-systems will not be delayed as *The Company* is not dependent on the 3rd party information from the shipyard, as the I/O list is based on the sub-systems made by *The Company*. In this way, the late design changes and the duplicated time spent by the shipyard and *The Company* can also be reduced in the IAS delivery.

Validation and Verification

In order to verify and validate that the solution, the stakeholders (*The Company* and shipyard) were presented to the concept of a standardized I/O list and further asked if the new RE process met the research goal. The shared feedbacks were that the stakeholders perceived the solution as important in means of reduction of man-hours related to the I/O list management process.

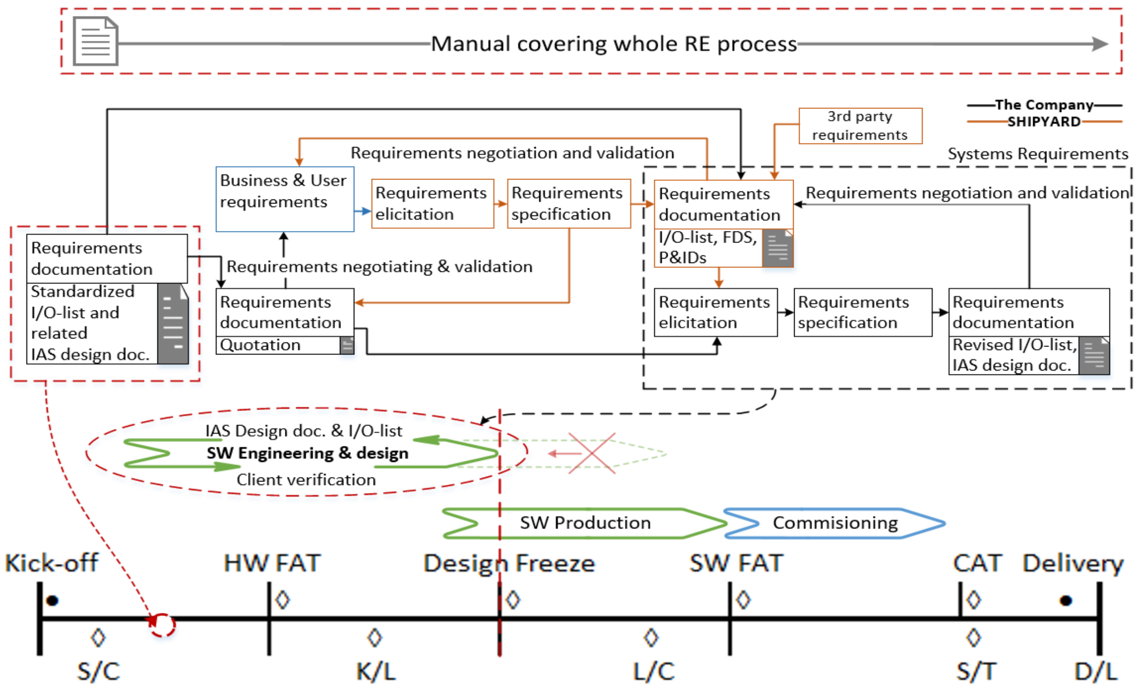

Figure 12. Enhanced Iterative Requirement Process

The participants of the survey in this case study were asked to prioritize the importance of cost reduction of the following activities: Functional Design Specification, Mimic Specification, I/O list Management or IAS Documentation. The answer was that reduction of man-hours related to I/O list management was the most important for both the shipyard and *The Company*. It also showed that the most time-consuming work related to the I/O list was to define correct I/O for each system, which is in line with this research and mitigated through the proposed solution.

Both *The Company* and the shipyards verified that the I/O list should be provided by *The Company*. By doing so, it will improve the quality of the project and decrease the time used on I/O list management. The participants were also asked in which area the IAS vendor should take more responsibility; for the shipyards it was most important that the FDS and allocation of signals should be of increased responsibility of *The Company*, while *The Company* wanted more responsibility related to the specification of standardized I/O, which is met through the optimized RE process. It is important for both *The Company* and the shipyard to reduce the man-hours related to I/O list management, and the survey has verified that it would be time-saving if the IAS supplier delivered a standard system were the I/O was standardized and matched in accordance with delivered HW (field stations and I/O modules). The majority of the survey participants states that a standardized I/O list will reduce the man-hours used in relation to the correspondence between the shipyard and *The Company*.

In comparison with the existing IAS-SW production, the domain experts evaluated a potential of 60% man-hour reduction when the solution has been fully integrated in the organization. By deploying the solution in a ‘real life’ IAS delivery, a reduction of 40% in the man-hours related to I/O list management has been obtained. It also shows that the requirements documentation is the only subject has minor changes after design freeze when the SW production of the standardized sub-systems starts at time.

Conclusion and Discussion

In this paper, a case-study is conducted for the IAS of the case company. The findings show that the I/O list management delayed the IAS-SW production due to the lack of ownership to the requirements documentation and the lack of standardization of RE process and requirements documentation. It is also found that the late initiation of the current RE process caused costly late design-changes due to inconsistency in the requirements documentation. The current RE process was ther eafter optimized in terms of gaining ownership to the requirements documentation by standardizing

the I/O list management process through engineering guidelines and I/O lists. This allows the iteration for the IAS design documentation and I/O list to start at an earlier stage and thus reduce the hours used related to I/O list management. By deploying the solution, the man-hours spent on I/O list management activities is significantly reduced and the delay of SW production of the standardized sub-systems is mitigated. The case company's sales engineer is now able to provide an accurate estimate of the I/O modules and I/O signals as these are already matched to the standard sub-system.

Based on the experts' evaluation, the solution has the economic value for both the shipyard and the case company by reducing the risks of delayed IAS-SW productions. It is also worthy mentioning the management challenges to successfully implement the solution. As the standardized I/O list is issued by the case company, it needs to be stated in the quotation and accepted by the shipyard. The shipyards also need to fully understand their responsibilities of the I/O list management process, which can be somewhat challenging, due to cultural and organizational differences (Ferris, 2007). Another important challenge is related to the internal change management and ownership of the different sub-system applications and requirements documentation like FDS and I/O list. The solution entails new requirements to the internal change management process, which causes extra man-hours for this change management. However, as the importance of time to market is increasing, the solution needs to be flexible, yet in line with the rapid development in the field of IAS systems. The change management regarding standardization and reuse are recognized as the most important criteria for automation systems development in 2020 (Feldmann, et al., 2012).

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Biography

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