AN ICOR APPROACH TOWARDS SHIP MAINTENANCE SOFTWARE DEVELOPMENT

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SUMMARY

Ship maintenance is one of the key processes to improve system performance and reliability onboard. Maintenance onboard ships is required to be performed in a planned manner because safe and efficient operation of a ship is very much depending on equipment reliability in operational level. A planned maintenance system (PMS), mainly supported with software, is established to monitor the maintenance implementations on board ships. This study aims to assess the effectiveness of onboard maintenance and limited with the procedures and specific softwares employed for the maintenance on board. Specifically, the process analysis approach is developed to execute the existing ship PMS phases based on four dimensions such as input, control, output, resources (ICOR). Besides the critical points to be improved in ship maintenance, this research reveals recommendations to increase the functionality of selected software in terms of workload balance, smart scheduling and safe working environment. To demonstrate the functional improvements, an illustrative case study on an auxiliary diesel generator maintenance routines are conducted. The contributions of the study are expected in both ship operations management and marine software development.

NOMENCLATURE

ICOR	Input, Control, Output, Resources
IMO	International Maritime Organisation
ISM	İnternational Safety Management
OM	Opportunistic Maintenance
PMS	Planned Maintenance System

1. INTRODUCTION

Maintenance is recognized as one of the major jobs facing an organisation to sustain the businesses effectively. It serves as a force multiplier and deemed as the primary contributing job to all processes of an organization to provide services or products at a higher level than its competitors. It also increases the reliability of all the systems used in service providing and in the production processes. Failure in doing maintenance adequately can cause significant costs. These costs are mainly caused by unpredictable failure of the system that is being used because of the missing maintenance and sometimes been unaffordable for a company in due course.

Due to the importance of maintenance, this challenging issue has forced many ambitious industrial organisations to place a high priority on preventive maintenance. In modern industrial organisations, maintenance departments have important roles because of their ability to have an economic balancing effect (Dekker, 1996). Even if there are specifically designed maintenance organizations and specific importances on maintenance processes, in many cases in actual practice, serious accidents and interruptions in many industries are related to poor maintenance, or, more specifically, to poor maintenance planning (Reason and Hobbs, 2003). Maritime industry faces unique challenges in the execution of scheduled and unscheduled maintenance; the mere fact that ships spend significant periods at sea far from the logistically supported areas (Rustenburg et al., 2001). A ship at sea is isolated from onshore repair and maintenance facilities, and, if a failure occurs during the passage, the required replacement parts may not be available on board. The rising cost of ship operation is a problem, since the failure of a vital piece of equipment can be very expensive and may put the safety of the whole ship at risk. Added to this is the cost of out of service (off hire), when the ship is in the downtime period because of the failure. Additionally, it may cause increases of the cargo expenses and may pose danger to the environment as well (Rothblum, 2000).

Maintenance is a crucial factor in a ship‘s performance and, in turn, can heavily affect the shipping company‘s revenue. There should be an optimal maintenance level for all the equipments on ships and therefore a balance between maintenance cost and over-maintenance. Over-maintenance is the term used for the case of excessive use of maintenance activities more than required level. Thus, establishing a good framework with which to measure maintenance performance to have an optimal level and to plan maintenance policy has vital importance for the shipping organization. In fact, approximately 40% of the operation costs in a maritime shipping organisation are attributable to maintenance (Alhouli et al., 2009). To keep the ship operating safely and efficiently with the lowest possible operation cost, ship maintenance is a critical process due to the various factors. Maintenance planning and its costs have great effects not only on technical management but also on commercial management of ships. Factors that affect the PMS for the planned maintenance optimization are vital to ensure that the maritime companies are able to save from the cost of maintenance budget. Indeed, developing a cost effective maintenance framework for ships has a critical importance in shipping organizations. The PMS is basically based on the calendar times of the objects or on actual working hours. The maintenance intervals are determined based on the calculation of the average failure times between the two maintenance periods (Mobley, 1990).

This study aims to develop a framework to aid decision makers in the maritime shipping industry to optimize maintenance planning for their organizations. Accordingly, the main objectives of the paper are as follows;

a) To identify the need and importance of maintenance with a specific focus on the maritime industry; and to extract and assess the factors that affects the decision-making process for ship maintenance planning.
b) To evaluate and compare different maintenance types for indicating the best maintenance planning method for an effective scheduling.
c) To identify basic & advanced tools of process analysis and improvement for using of developing maintenance planning system onboard.
d) To investigate the implementation principles of the ship planning maintenance system onboard and the software supports.

The paper is organized as follows: The initial part underlines the importance of equipment maintenance on board. Then, the existing theoretical developments in maintenance management and ship maintenance applications are discussed in the literature review. After providing brief information about process improvement techniques, ICOR approach is structured through ship maintenance process. After data analysis, findings are recognized and listed to utilize in maintenance planning and software functional development. Additionally, a specific maintenance planning of chosen equipment (i.e. a diesel generator) and its application is taken as an example in the study and evaluations made are compared with the other findings to produce results.

2. LITERATURE REVIEW

Recently, maintenance operations management is a highly cited research theme in the literature. The industrial representatives have closely interested in the studies provide new approaches to the ship maintenance supported with the field studies. Garg and Deshmukh (2006) encouraged the researchers and maintenance professionals to understand the importance of maintenance management.

Regarding the theoretical insights, various number of review studies on the developing concepts are addressed such as e-maintenace (Levrat et al., 2008), machine prognostics (Peng et al., 2010), maintenance optimiztion (Sharma et al., 2011). In detail, the maintenance process seeks for the innovative approaches and models to manage maintenance performance (Simões et al., 2011). In addition, maintenance strategy selection (Bevilacquaa and Bragliab, 2000; Al-Najjara and Alsyoufb, 2003; Wang et al., 2007; Arunraj and Maiti, 2010; Chemweno et al., 2016) is a focused optimization problem in different industries. Ab-Samat and Kamaruddin (2014) introduced the applications of opportunistic maintenance (OM) as new advance maintenance approach and policy. On the other hand, the importance of human factor in maintenance deals with the human error, macro-ergonomics, works planning and human performance (Sheikhalishahi et al., 2016).

In literature, there are limited number of research studies on the ship and offshore maintenance aspects. Deris et al. (1999) developed an algorithm to enable ship availability via maintenance scheduling process. The effects of maintenance to ship reliability was studied by Jiang and Melchers (2005), Lazakis et al. (2010) while Lee et al. (2013) suggested RFID supported cloud technology towards ship maintenance inspection. Goossens and Basten (2015) have cooperated with the owners, operators, shipbuilders and equipment manufacturers from the maritime community to identify the parameter triggers a maintenance action. Lee et al. (2016) proposed a maintenance system for LNG-FPSO via equipment-oriented condition based maintenance methodology. Regarding with the integration into safety management system, Akyuz and Celik (2017) promoted an e-PMS concept to monitor and imrove ship systems’ conditions. Besides theoretical insights, the ship operators and shipboard personnel have interested in the utility of the maintenance systems onboard ships that are so critical issue. Especially, software tools to transform ship maintenance are highly important (Ali, 2015). The end user requirements of interfaces influence the effectiveness of maintenance system implementations. On this issue, the ongoing efforts of maritime research institutions, marine technology manufacturers and classification societies have been addressed. Therefore, this study is to be focused on identifying the critical points to be improved on ship planned maintenance system supported with software. The advanced studies (Lazakis et al., 2016; Lazakis and Olcer, 2015; Varelas et al,, 2013) through ship maintenance, operations and inspections onboard are also available in literature.

3. PROCESS IMPROVEMENT

3.1 TECHNIQUES

The definition of a process consists of structured tasks that produce a specific service or product to address a certain goal for a particular actor or set of actors (Glykas, 2013). The development of a system depends on the improvement of the processes in this system. The new and different ideas, views, and methodologies are required for development. Accordingly, the process improvement has the following characteristics: implementing incremental changes, starting with the existing process, carrying out one-time/continuous application, etc. (Damij and Damij, 2014). In process improvement, the practitioners have been using various tools and techniques. Just to name a few; DRIVE (define, review, identify, verify, execute), Process mapping, ICOR (inputs, outputs, controls and resources), Process flowcharting, Force field analysis, Cause & effect diagrams, CEDAC (cause and effect diagram with addition of cards), Brainstorming, Pareto analysis, SPC (statistical process control), Control charts, Check sheets, Bar charts, Scatter diagrams, Matrix analysis, Histograms, etc. (Assi, 2016; Boutros and Cardella, 2016).

In the application of techniques, it is required to break down the core processes into sub-processes, activities and tasks. Once an organization has defined and mapped out the high-level core processes, people need to understand what activities are required within these core processes and how they combine at operational levels (Oakland, 2014). This study takes the advantage of ICOR (inputs, controls, outputs and resources) in process analysis of ship maintenance.

3.2 PROCESS IMPROVEMENT TOOL: ICOR (INPUTS- CONTROLS- OUTPUTS- RESOURCES)

Considering the process improvement tools and techniques, it was deemed that ICOR is a convenient method for analyzing planned maintenance system onboard ship. ICOR (inputs, controls, outputs, and resources) is a process analysis methodology allows processes to be broken down into simple, manageable and more easily understandable units. During the analysis, all the sub-processes that constitute the main process and the components in the pool are examined. All the sub-processes in the pool are distrubuted seperately to the components of the ICOR system, Input, Control, Output, Resources. For instance, the regulations and relevant management systems are considered as Control while the Resources represent competencies in the different levels of organization (Badiru and Osisanya, 2013). By doing so, important shortcomings and the sub-processes needs to be improved to solve the problems could be easily defined for a PMS.

3.3 ICOR APPLICATION TO SHIP MAINTENANCE

The sub-processes, cases and the add-ons affecting the planned maintenance system onboard ships are as follows:

- Equipment conditions
- Running hours
- Spare Parts (Supply Chain)
- Manpowers (Number of Manning)
- Financial Budget
- Marine Suppliers (Vendor Evaluation)
- Knowledge & qualification (Training of Crew Members)
- Audits (internal Audit, External Audit)
- Safety Check List (Deficiencies)
- Performance Checks (Malfunctions)
- Procedure & Regulations (Documentation, Administration Requirement)
- Maintenance Schedule (Smart)
- Operation Planning
- Scope of Maintenance

To be able to analyze the PMS process by the ICOR method, it is necessary to determine in which group the above-mentioned sub-processes and annexes belong to and under which previously determined components they should be grouped. After sub-processes and annexes are grouped, the diagram in Figure 1 is drawn to show the analysis of what the sub-process affects and what other processes are needed to be developed.

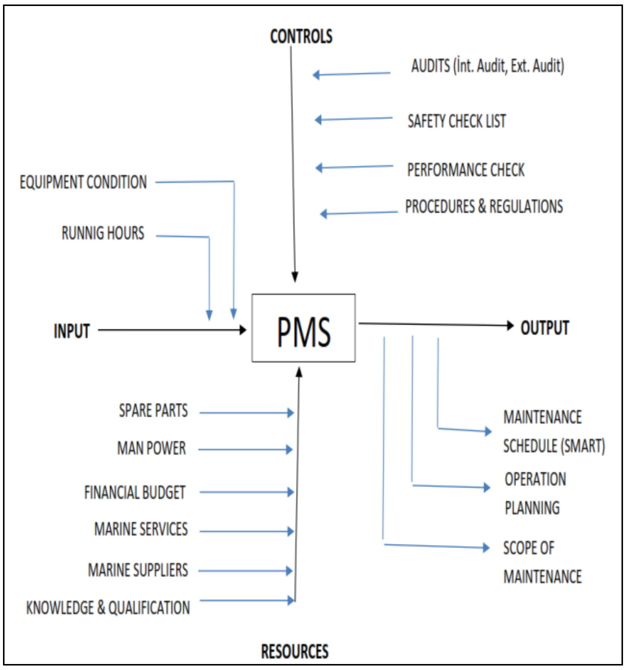

Figure-1: ICOR Analysis on Ship PMS Implementations

In the analysis, excessive and unbalanced workload has been attracted a special importance to identify and to solve the problems. Additionally, improper and untimely maintenance planning and safe maintenance operation problems detected and reported by 3rd party inspections and company / sector experience were noted. For analysis purposes, an ICOR control matrix was developed and shown in the Table 1.

In the first row of the table, the problem to be improved is inserted. The second row contains the corresponding sub-process in the Input group of the ICOR drawing, the third row of the corresponding sub-process in the Control group, the fourth row of the corresponding sub-process in the Output group, and the fifth one sub-process of the Resource group.

Table 1: ICOR Control Matrix

PMS SUBJECT	Workload Balance	Smart Schedule	Safe Maintenance Operation
INPUT	Equipment Condition Running hours of Engine	Equipment Condition Running hours of Engine	Equipment Condition
CONTROL	Safety Checklist	Performance Check	Safety Checklist Procedures & Regulations
OUTPUT	Scope of Maintenance	Operation Planning	Operation Planning
RESOURCE	Manpower	Spare Parts Financial Budget	Manpower Marine Services Knowledge & Qualification
ACTION	Safety checklists must be prepared specifically for ship equipment& crew members. (Critical & stand by equipment) Running hours of the engine and equipment conditions must be considered to determine the scope of maintenances done by the crew members, Sufficient manpower must be provided considering related equipment condition.	Performance checks of equipments must be considered Operation plan should have no conflict with the work schedule. Supply of Financial budget and spare parts for all equipments considering their Running hours has priority in all activities of PMS	Safety checklist properly must be prepared prior to maintenance Safety procedures must be adopted Qualified manpowers must be provided Marine service evaluation must be considered

The categorized processes in the table were analyzed to determine the necessary corrections for the targeted improvement. In order to overcome workload imbalances, it was found that preparation of safety check lists, scope of maintenance and amount of manpower are the three main items needed to be improved. For smart scheduling, possible corrections to be done are centered on the improvement of performance checks of equipments, consistency of operation plan and PMS work schedule and supply of spare parts. The safe maintenance operation deficiencies were analysed and timely preparation of the safety checklists, adaptation of PMS procedures to the ship safety system application, qualified manpower needs and requirements to outer management support subjects were found as sub items to be improved. All those sub items are discussed in the following subsection.

3.4 FINDINGS

The objective of the aplication was to find what should be improved for solving the problems and to restructure an enhanced planning maintenance system onboard ship. By applying the ICOR method to planned maintenance systems onboard, three important shortfalls have been analyzed as explained in the previous section.

3.4 (a) Workload Balance

Workload balance is the first of the above-mentioned shortfalls. Balancing workload onboard is the key component of defining the number of crewmembers onboard the ship. Minimum safe manning certificate is the document of the vessel which is issued by the flag state of the vessel that shows the minimum number and competency of crewmembers for engaging intended voyage in international waters. Most of the times, number of crewmembers indicated on the minimum safe manning certificate is not enough for maintenance and routine operation of the vessel and this situation does not comply with regulating international documents such as Maritime Labor Convention- 2006 of ILO.

Ship's management companies, if it is the case, generally issue common safety checklists and control forms for their ships under management. Unfortunately, those control forms sometimes cause a waste of time for responsible persons. Also this may lead to insufficient or unnecessary controls of equipment & tools. Hence, checks lists must be prepared by considering the specification of the ship equipment and crewmembers to reduce the workload (for critical-stand by equipments).

In order to identify the exact required number of employees onboard, ship's master and operators should consider the ship condition, voyage pattern and number of running equipment by taking into account the allowable maximum number of persons onboard which is indicated in the ship safety equipment certificate.

3.4 (b) Smart Scheduling

Regularly done performance checks or using of condition monitoring systems are the main ways of structuring maintenance programmes of ships. This ensures that, focusing to the maintenance of which equipment needed. Operation planning is another important part of the smart scheduling of the maintenance onboard ship. Most of the times, planned maintenance made without considering vessel's operation may cause that maintenance could not be carried out within planned periods and remain of overdue maintenance. On the other hand, lack of consideration for the shipboard operations and tool availability causes delays and suspensions of shipboard operations. An effective maintenance planning ensures the maintenance of ship's equipment & tools is successfully performed without suspension of the operation of the vessel.

Smart scheduling also requires some kind of supply activity. Before preparing a maintenance plan and starting maintenance of equipment & tools, necessary spare part must be available onboard. Therefore, at the beginning of the fiscal year, ship budget must be prepared considering needs based on the principal maintenance plan.

3.4 (c) Safe Maintenance Operations

Providing safety is not only an aim but also a process of maintenance onboard. Safety measures to be taken have special importance in the maintenance activities on board ship. Carefully prepared procedures for before, during and after maintenance activities and safety control check lists play key roles of the safe maintenance operations.

Some of the maintenance operations onboard are carried out by third parties like as marine technical services. Under these circumstances, quality of marine technical services and approval of specific manufacturer authorizations play a key role. Additionally, Company's marine technical services' evaluation reports provide important feedback for future operations. Their qualification, experience and knowledge levels on safety issues provide important inputs to ensure safe maintenance operation.

3.4 (d) Other Issues

In addition to the findings above, todays contemporary ship management compared to past experiences becomes a more important job in which has considerable amount of detail is managed and completed with many factors. Main goal of any given company to achieve profit with simple methods has become difficult for the shipping industry. Safety, quality, assessment and measurement, follow ups, procurement, giving swift yet true decisions are only some of the critical business requirements. These goals are slowly but steadily becoming impossible to achieve mainly by human operators; thus, data processing automated systems are becoming a necessity. Multiple ship management companies working in collaboration within this application framework to resolve these critical issues to attain a perfect standardization would result in optimum solutions.

3.5 INVESTIGATION OF FINDINGS

After analyzing the problems, the main functions of the system to be developed were found as follows:

- F1: Reducing operating cost and increasing operation time of equipment.
- F2: Reducing defects and downtime,
- F3: Defining root cause of the problem,
- F4: Ensuring safe operations of ship.

In order to develop the planned maintenance functions described above, the process improvement techniques denominated common goals are utilized. When examining both basic and advanced improvement techniques, it was realized that the common goals of many techniques could be as follows:

- M1: Strengthen cross-functional teamwork, problem solving, and collaboration capabilities,
- M2: Develop effective process controls to prevent recurrence of known problems,
- M3: Analyze the process for efficiency, effectivity, and waste,
- M4: Enhance process effectiveness,
- M5: Simplify planning and scheduling,
- M6: Establish standardization.

Under the light of the above consideration, Table 2 has been drawn. Common goals and functions that are problematic in the systems are compared with each other and the evaluations are reflected in Table 2.

Table 2 Functional Improvement Options Matrix

	Improvements					
Functions	*M1*	*M2*	*M3*	*M4*	*M5*	*M6*
F1	X	X	X	X		X
F2	X	X	X	X	X	
F3	X	X		X		
F4	X	X		X	X	X

Providing in Table 2, defined improvements can be applied to variety of functions in the PMS. The implementation of specified improvements could be made on the selected software.

Within the scope of these improvement options, not only the development of the PMS but also the development of a complex ship management system, and the optimization of critical safety problems could be utilized by software development teams and shipping company's technical managers. Increasing the reliability of automation systems with the help of ship management software is an important subject of today for the requirements of contemporary maritime industries are met. The optimization and development of more effective PMS systems which are out of the scope of this study could be addressed in the future.

4. SOFTWARE DEVELOPMENT

4.1 EXISTING PRACTICE

Today, PMS is performed by many of the shipping companies with support of the computer aided systems. As an example, one software application was chosen to produce meaningful results in this study. The ICOR analysis results were used to investigate and to improve the maintenance software functionality, which is used in the ship management company. In practice, all the equipments onboard are included in the planned maintenance system. Maintenance intervals of each equipments are planned and scheduled by PMS with support of special software. As an example, in the study, a specific planning and execution of a diesel generator maintenance was examined to check the findings.

An engineer onboard has to be capable of doing overhaul of a diesel generator during routine maintenance or in case of emergency situation. This competency is compulsory for all level engineers working on ships. Overhauling of generator not only means cleaning and removing carbon from parts and spaces involved in combustion of fuel but also includes checking, fixing and renewing of parts involved in power transmission like connecting rods, con-rod bearings, main bearings etc. According to a research (Wankhede, 2013), 50% of marine engineers who are at the initial stages of their sea careers are unaware of the procedure for overhauling generators. Many of them do not have enough confidence to carry out the overhauling alone or are reluctant to take the responsibility without the assistance of senior personnel. This shows that capable person in doing an effective maintenance onboard has a special importance.

4.2 ILLUSTRATIVE EXAMPLES THROUGH SOFTWARE FUNCTIONS IMPROVEMENTS

Overhaul process of a diesel generator which is examined is as follows:

a) Monthly reports sent by ship to the company as paper form including performance records and working hours are recorded to the PMS.
b) Overhaul is planned by considering performance records and running hours of the engine.
c) Necessary spares are listed and their availability are checked. Requirements are defined and ordered via company procurement and supply branch.
d) Time frame and location of the overhaul is planned.
e) Overhaul process is executed according to its scope.

The fact is that overhauling of ship's generators is not a part of a daily routine task of engineers. It is a long and tiresome procedure which is carried out when the generator reaches the time for scheduled maintenance except of sudden breakdown of it. Overhauling of generators requires hands-on knowledge and experience along with thorough understanding of step-by-step procedures for maintenance of auxiliary engine overhaul which this complexity was solved by help of software. Before and during the overhauling process, a variety of tests are performed on various tools and parts of the generator such as; hydraulic jack test, cylinder head test, bearing cap test, con-rod bolts test, connecting rod bend test, fuel Injector test, starting air valve testing, relief valve test, the current test, alarm and trips test.

Ensuring that safe working practices are followed while carrying out generator overhauling is important for engineers on board ship. As such processes usually require working as a team, miscommunication in the maintenance team can result in unfortunate accidents. It is therefore necessary to follow systematic guidelines and step-by-step procedures for carrying out such complex work in the engine room. The following procedures to be checked to figure out the problems show the complexity of the diesel generators' overhaul. There are many reasons, which will lead to reduced power output and performance of a diesel engine on board ship such as; fuel oil pressure too low, type of fuel used onboard, fuel leakage,fuel temperature, firing pressure difference, blocked filter, wrong valve clearance, damaged exhaust valve, high exhaust back pressure, contaminated passages, insufficient fresh air supply, high suction air temperature to T/C, charge air pressure too low, wrong charge air temperature, charge air cooler contaminated, air cooler S.W temp high, blower turbine or nozzle ring worn/ damage, scavenge air leakage, wrong tappet clearance setting etc.

4.3 REVIEW OF IMPROVEMENTS

After examining the maintenance application of diesel generator onboard, the software application on PMS and the ICOR findings, for a qualified planning and execution of maintenance, the following areas should be considered:

a) Auxiliary diesel engine breakdown may occur anytime each year. Because there is a thin line between the starting of a problem and the problem taking the shape of major issue and it BE was only a ship's engineer who can assess this situation. Regularly done performance checks or using of condition monitoring systems are the main ways of structuring maintenance programmes of ships. This ensures that, focusing to the maintenance of which equipment needed. Thanks to software equipment performance and running hour informations received as simultaneously on basis daily. M2 and M6 improvements from Functional Improvement Options Matrix require special attention.

b) Major overhauling operation should not only be decided by taking into accout the equipment performance and running hours for a ship used to for commercial activities, but also the commercial activities and agreements except sudden failure and unfortunate accident case. Although safety and security of the ship is primary concern, it is vital importance to evaluating the ship commercial activities. The software which had been structured with ICOR philosophy should meet this requirement. This requirement is also dictates the improvement of M3 and M4 of Functional Improvement Options Matrix.

c) Overhaul of an auxiliary diesel engine brings about many problems to be solved. More systematic structure is necessary for accurate and quickly determination in problem solving due to nature of the problem. There may be encountered some problems that require immediate actions during overhaul of diesel generators. Simultaneous follow-up and records of maintenance history provide holistic view and sharp forecast about the root cause of the problem. So, defining the scope of the overhaul, necessary spares for the completion of the operation more certainly were known. In other words, it has helped for mentioned preparation as decision support system. Before preparing maintenances plan and starting maintenance of equipment & tools, necessary spare part must be available onboard. Therefore, at the beginning of the fiscal year, ship budget must be prepared with considering needs based on the principal maintanance plan. By means of integration between ship to shore and software data has contributed improvement of M1 of Functional Improvement Options Matrix.

d) Planning of the overhaul operation is made without interrupting any other ship operation by taking into account the voyage and operation information data which are obtained from the integrated system. This could be achieved only with having the maintenance be finished within planned time frame. Most of the times, planned maintenance made without considering vessel's operation may cause that maintenance could not be carried out within planned periods and remain of overdue maintenance. On the other hand, it could cause suspension of operation of vessel due to the maintenance lacks of equipment & tools when maintenance activities have been started without considering operation of the vessel. An effective maintenance planning ensures the maintenance of ship's equipment & tools is successfully performed without suspension of the operation of the vessel.

e) A successful and safe overhaul operation depends on the certainty of the scope of the overhaul operation and arrangement of proper manpower. Equipment performance and running hour data helps to identify scope of overhaul. Then, this scope defines the necessary average manpower reuirement. Holistic approaches ensured decision support mechanism about to make equipment overhaul operation within the planned time interwal by either the crewmember or outsourced manpower considering crewmember's other duties and their working hour of them. Applicability of the improvements of M5 and M6 were observed here. In order to identify the exact required number of crew to be employed on maintenance activities onboard, ship's master and operators should consider the ship condition, voyage pattern and number of running equipment. Actually, not only the minimum safe manning certificate of the ship but also an effective planned maintenance system defines the number and quality of the ship crew. Shipowners should take into account the requirements of PMS onboard primarily in defining ship crew.

f) Safe maintenance operations are the most important part of the maintenance onboard ship. Carefully prepared procedures for the before, during and after maintenance activities and safety control check lists play key roles of the safe maintenance operations.

5. CONCLUSIONS

This study concentrates on the PMS implementations which influence efficiency, reliability, safety and organizational effectiveness. The planning factors for an effective PMS are consisting of selecting a convenient strategy for maintenance, making the smart maintenance schedule, selecting qualified ship's crew member, selecting convenient shipyard for dry dock of the ship and desinging the ship with consideration of maintenance planning from the construction stage. Indeed, the effective maintenance has great potential to increase the system reliability.

Using of ICOR model in software system as core philosophy ensures solving of each item in detail with holistic approaches which consider interaction with other components. Identified improvements has found applicable from M1 to M6 to reach the targets identified from F1 to F4 shown in the Functional Improvement Options Matrix defined in the previous part of the study.

Practical applications reveal various operational improvements such as workload balance, smart scheduling and safe maintenance operation. Through the integrated system software with using of ICOR method philosophy not only lessons for the development of PMS but also contributions for the improvement of the preventive / predictive maintenance were obtained. Thus, early and sharp forecasts about reason of the breakdown and or malfunctions could become available.

The study also demonstrates the several points to be improved along with the existing fuctions of the utilized softwares, given as follows: i) Reducing operating costs and increasing operation time of equipments, ii) Reducing defects and downtimes, iii) Defining root cause of the problems, iv) Ensuring safe operations of a ship.

ICOR method is not only used for maritime sector but also can be used in many branches of the industries such as logistic, transportation and nuclear energy. Furthermore, it could be used as infrastructure of artificial intelligence or decision support systems, for analysis of enhanced integrated data such as new source, outputs, inputs and controls day by day. Todays industries are getting more complex each day because global economy provides new inputs, outputs and sources to be managed for them. So, new and talented management systems are not only requirement for planning and execution of maintenance for shipping companies but also general requirement for all the industry.

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