FRAUNHOFER CENTER FOR MARITIME LOGISTICS AND SERVICES CML

MAINTENANCE MANAGEMENT. MATHEMATICALLY OPTIMIZED.

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INTRODUCTION

Ship management comprises five core tasks, namely crewing, technical management, financial management, quality & safety and procurement. Out of these core tasks, many shipping companies consider crewing and technical management as the most challenging tasks for the mid-term future.

Image 1: Ship Management Circle

For technical management, one of the key competencies is to find the optimal maintenance strategy. Unplanned maintenance causes a significant part of ship operation costs. Including spare part procurement, unscheduled or corrective maintenance account for up to 25 % of the total ship operation costs (Drewry Maritime Research, 2015). Finding and implementing an optimal maintenance strategy is therefore a crucial task in technical management and has a great impact on the success of the entire ship management.

The goal of maintenance management is to balance costs of preventive maintenance or of external maintenance services with costs of equipment failure. The challenge is therefore to find appropriate maintenance intervals that prevent unplanned maintenance and costly downtime of equipment. Another problem is to distribute the workload evenly under consideration of the vessel's voyage in order to efficiently deploy human resources and to avoid rescheduling of jobs. Increasing requirements by classification societies, charters and compliance pressures add to the complexity.

A further task of ship management is crewing. It contributes a significant part of the fixed operating costs. In order to manage crew resources effectively and compliant with rest hour regulations, the crew demand assessment is an essential part of crew management. Increased capacities of merchant ships as well as tighter port frequencies led to higher workload in the last decades. In combination with new legislative regulations, this makes the crew demand assessment solely by knowledge and experience even more difficult.

In comparison to other industries, the maritime industry has the unique trait that the same crew is responsible for both operating and maintaining the vessel. Consequently, maintenance management is closely intertwined with crewing management. In addition, route and freight planning has an impact on the crew's workload and their capacity for preventive maintenance. Therefore, it is a challenge to take the interdependencies between maintenance, operational and crewing management into account when managing a ship.

To tackle these challenges, the days of paper based processes are outdated and computer based information management systems play a key role. In previous years, we have already addressed the need for data based decision support in crew demand assessment. We developed a software tool that computes mathematically optimized crew schedules and derives the voyage and ship specific crew demand: SCEDAS®. It has been deployed in fleets of several ship types and is constantly being further developed.

In our recent developments, we approach a data based decision support system for maintenance management. It provides support in efficient and compliant maintenance scheduling under consideration of the crew's voyage specific workload and distributes jobs evenly. It considers requirements by company policy, classification societies, charters and legislative regulations. For that, we build up on the development of SCEDAS® and develop an interdisciplinary software tool.

MAINTENANCE STRATEGIES

An essential task of maintenance management is to find the optimal maintenance strategy. It should keep the vessel at constant operating state and avoid costly unscheduled maintenance and downtime of equipment. However, it should also be cost-efficient and keep unnecessary maintenance measures at a minimum. The key is therefore to take maintenance measures only when they are necessary without risking costly equipment failure. But how is this possible?
In general, maintenance strategies can be categorized into corrective, preventive and predictive maintenance.

UNPLANNED MAINTENANCE

Corrective maintenance implies to take action in the case of equipment failure. This strategy does not pursue any measures to prevent failure. This causes costly unplanned maintenance. However, for the cases when no recommended maintenance interval, no knowledge about the equipment's wear behaviour or about its condition is available, it is the only possible maintenance strategy.

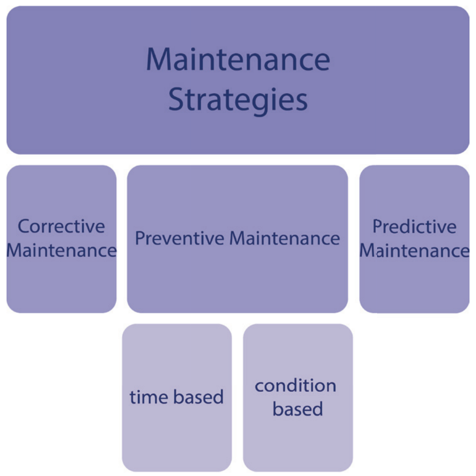

Image 2: Maintenance strategies categorized by DIN (German Institute for Standardization)

COMMON STRATEGY: PLANNED MAINTENANCE

On the other hand, preventive maintenance strategies require maintenance actions that prevent equipment from failing. This means regular maintenance of equipment within specified intervals. These maintenance intervals can be either time based or condition based. The time based preventive maintenance is called planned maintenance. In the case of planned maintenance, the maintenance intervals are predefined through vague estimation of the equipment's expected lifespan and do not consider its condition in the course of ship operation. The intervals are e.g. in time or in running hours. Because the equipment's condition has no influence on the maintenance intervals, this maintenance strategy does not exhaust the maximal operating periods and can lead to unnecessary workload. This entails avoidable costs for shipping companies. Yet, this is currently the most common maintenance strategy in ship operation.

TREND: CONDITION BASED AND PREDICTIVE MAINTENANCE

Nonetheless, the trend is going towards condition based or even predictive maintenance because of advances in sensing and computing. Condition based maintenance is a form of preventive maintenance in which the maintenance intervals are dependent on the equipment's condition. It implies to continuingly sense the equipment's condition (e.g. temperature, vibration, acoustic emission) and automatically derive appropriate maintenance intervals from the sensor data, e.g. by defining thresholds or characteristic patterns. In the aviation industry, condition based maintenance has already been successfully deployed for some time.

Predictive maintenance takes condition based maintenance to a higher level. Algorithms constantly evaluate the sensor data and predict the remaining lifetime of the equipment from stochastic degradation models. By this, chief engineers onboard know when the equipment's condition requires maintenance and can schedule maintenance only then when necessary. Taking the crew's workload through operations into account, they can schedule maintenance optimally. Consequently, the trend is shifting from constant maintenance intervals to varying intervals dependent on the equipment's condition. This complicates the scheduling of maintenance. A scheduling tool that reacts instantly to varying maintenance intervals is thus a valuable support.

DIGITALIZATION IN MAINTENANCE MANAGEMENT

PLANNED MAINTENANCE SYSTEMS

For ship maintenance, so-called planned maintenance systems (PMS) are already well established. Their original purpose is to manage planned maintenance tasks. They provide a central overview over recurring maintenance tasks of the vessel and a tool for on board documentation. Thereby, these systems serve as a central communication platform for all technical matters and provide valuable support for shipping companies. PMS become more and more integrated with extensive software, such as procurement and purchasing systems and quality and safety software systems. Some PMS already support analysis tools for condition monitoring, such as visualization of compliance with predefined thresholds or trend functions.

CONNECTING MAINTENANCE MANAGEMENT WITH SHIP OPERATION

Our aspiration is to take the developments in the digitalization of maintenance management a step further and integrate maintenance scheduling into crew and voyage planning. This can be achieved with an interface between the PMS and crew scheduling. By that, the impact of maintenance management to the crew demand as well as the impact of operational management to the maintenance workload can be quantified. By calculating different scenarios, different maintenance strategies are comparable and maintenance management can be optimized. Thereby new maintenance strategies can be tested and evaluated before implementing them onboard. The rise of automation and connectivity goes hand with hand with decreasing crew sizes, placing the crews competences and workload at the heart of maintenance management.

PREREQUISITE: HARMONIZED DATA

However, a prerequisite for successful further development of digitalized maintenance management is fleet wide administered maintenance data. In order to gain synergies between vessels, it is essential to have harmonized maintenance specifications of all vessels of a fleet.

UNITING TECHNICAL MANAGEMENT, OPERATIONAL AND CREWING MANAGEMENT

VISION: DATA BASED DECISION SUPPORT IN MAINTENANCE MANAGEMENT

When finding the optimal maintenance strategy manually, it is almost impossible to take all cost and compliance pressures as well as the impact on operation and crewing into account. We are now introducing a software tool that provides mathematically proven decision support in maintenance management under consideration of all of those constraints. Our development builds on a previous software solution that creates optimized voyage specific crew schedules and assess crew demands.

SCEDAS: CREW SCHEDULING AND DEMAND ASSESSMENT

The crew management and scheduling system SCEDAS® is invented and constantly being further developed by Fraunhofer CML. Its purpose is to provide well-founded decision support in ship management matters, especially crewing questions to customer specifications and needs. It mathematically determines the ideal crew demand on board and optimizes ship and voyage specific work schedules under consideration of constraints.

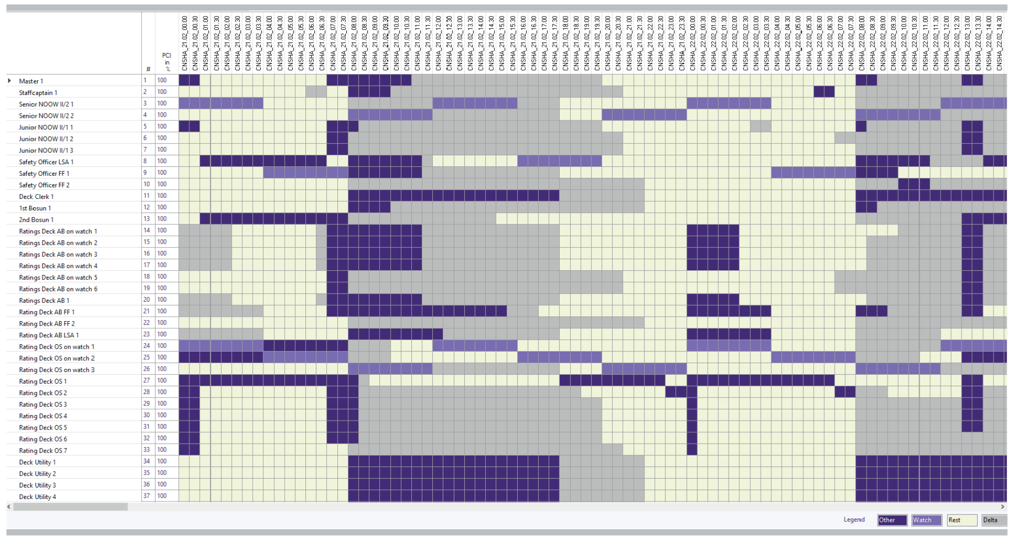

Image 3: SCEDAS® schedules the voyage dependent workload under the consideration of the crew's qualifications and rest hour regulations (watch displayed in light purple, other operational tasks dark purple, rest hours in beige and available time for maintenance in grey)

A task based approach takes the workload, the crew's qualifications and voyage specific dependencies as input. Per task, alternative qualification requirements can be assigned in order to increase the degree of freedom. Mathematical algorithms create a voyage dependent schedule under the consideration of legislative regulations for rest hours and company specific requirements. From that, the voyage specific crew demand and capacity for maintenance is derived. The mathematical model has been validated both in the merchant and the cruise ship domain.

The software is used as an onboard tool to create work schedules on the fly that take the current work and rest hours of the crew into account. Moreover, it is used as a strategic tool to quantify the impact of fleet wide ship management questions to the crew demand.

SCEDAS® can already model the interdependency between ship operation and crewing. As a next step, we will draw the connection to maintenance management.

APPROACH: COMBINED SCHEDULING OF SHIP OPERATION AND MAINTENANCE

Our approach is to integrate the scheduling of maintenance into the algorithms of SCEDAS® scheduling and crew demand assessment.

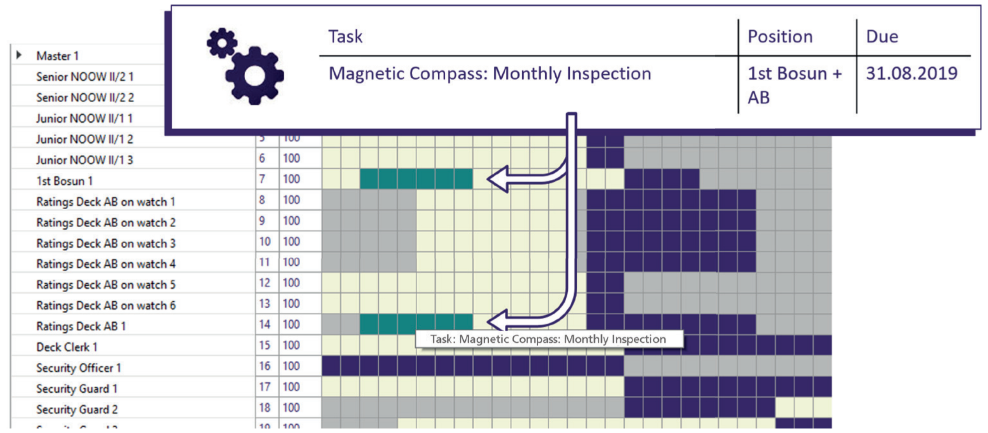

Image 4: Integration of maintenance into crew work schedules

The SCEDAS® algorithms schedule all relevant tasks for safe ship operation and derive the ideal crew demand from this. Once those operational tasks are scheduled, the crew's capacity for maintenance (displayed in grey) becomes apparent. Our approach is to assign PMS jobs (displayed in green) to these time slots under the consideration of their maintenance intervals and prioritization. SCEDAS® will then provide mathematically optimized maintenance schedules under consideration of voyage specific constraints.

In order to avoid redundant data administration in separate systems, our aim is a cohesive system with an interface to the PMS. Then, SCEDAS® can automatically read out maintenance tasks. In order to schedule maintenance tasks, the algorithms need information on qualifications and duration per task. Through a user interface, the maintenance data can be completed and task specifications, crew and voyage data can be edited.

PROCEDURE FOR IMPLEMENTATION

The scheduling algorithms assign tasks to seafarers based on their qualifications. Therefore, all tasks that are relevant for ship operation need to be defined. A realistic definition of the tasks is of high importance in order to get good results. On the other side the optimization is enabled if the specification of the inputs e.g. tasks is done up to a certain aggregation level with some degrees of freedom for the calculation. The definition of tasks with these properties is of course very challenging. This process can be supported by an onboard software tool that collects the crew's work hours to task specific detail. Where applicable, the tasks are associated to ship operating states (e.g. port stay, transit, berthing, pilot takeover,…). Then, the tasks are assigned to groups of crew positions. Hereby, alternatives can be listed with prioritization (e.g. if the first bosun is unavailable, the second bosun can execute the task). The task definition as well as the definition of positions is considered as the base data.

Then, the interface to the PMS is set up. All information relevant for scheduling can automatically be read out of the PMS database, e.g. maintenance tasks with their due dates and their frequencies. However, in order to schedule the maintenance tasks, information on the duration and qualification requirements per task is necessary. The user can also define a prioritization of maintenance tasks. This information needs to be entered manually via a user interface. Here, all (maintenance) data can be administered and manipulated to prepare different calculation scenarios.

At this point all relevant information is prepared. Next, different port rotations are created. Here, the sequence of ship operating states and corresponding work packages are defined. From this, the algorithm creates a work schedule that corresponds to the base data definition and maintenance input. The tool can be used either in the office to assess the crew demand for specific ship and voyage, or onboard to create work schedules on the fly.

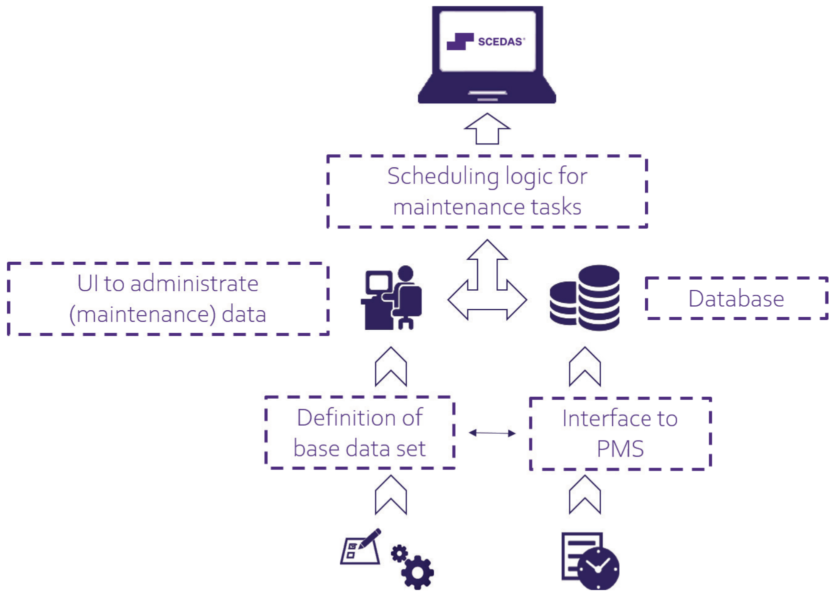

Image 5: implementation process of SCEDAS® with integrated maintenance scheduling

MAINTENANCE SCHEDULES RESPECTING:

- WORKLOAD AND AVAILABLE RESOURCES
- TASK SPECIFIC QUALIFICATIONS
- WORK AND REST HOUR REGULATIONS
- SHIP SPECIFIC MAINTENANCE POLICIES
- PORT ROTATION
- MAINTENANCE PRIORITIZATION

BENEFITS AND POTENTIAL

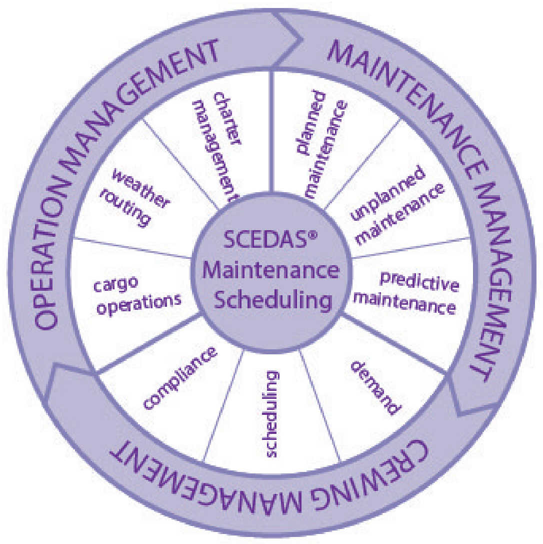

Image 6: Unity of Operation, Maintenance, and Crewing Management

OPTIMIZED MAINTENANCE SCHEDULES

The integration of maintenance into crew scheduling would increase efficiency in ship management and entail several benefits for ship management. It facilitates the consideration of requirements and regulatory of the company's policy, classification society or charters of the vessel for maintenance scheduling. It helps to deploy human resources on board more efficiently and ensures work and rest hour compliance. This decision support thus makes the maintenance scheduling process easier for superintendents and chief engineers. As a result, maintenance within due dates is assured and the reliability of vessel maintenance increases. Therefore, unplanned maintenance and costly downtime of equipment is prevented.

FLEXIBILITY

The possibility to generate schedules on demand during the passage allows flexibility regarding unforeseen changes in voyage, workload or human resources. This allows quick reactions to work and rest incidents or unplanned maintenance.
This is particularly useful as maintenance strategies are developing towards condition based main-

tenance. In this case, the maintenance intervals vary dependent on the equipment's condition. The on board scheduling with SCEDAS® can react to varying maintenance due dates and adjust work schedules.

TOOL TO ANALYZE MAINTENANCE STRATEGIES

In addition, this information management system provides profound decision support in interdisciplinary ship management. This tool can quantify the interdependencies between crewing, operational and maintenance management in terms of crew demand. Superintendents can effortlessly compute different scenarios and evaluate the impact of maintenance management to the ship and voyage specific crew demand.

Computing scenarios can analyze different maintenance strategies before implementing them on board, e.g. adjustments of maintenance intervals, balancing maintenance efforts against external services, how maintenance tasks should be assigned to crew qualifications or if cost-optimized bundling of certain maintenance tasks is feasible.

HARMONIZED FLEET WIDE MAINTENANCE AND CREWING DATA

Implementing an interdisciplinary crewing system makes a significant contribution to the harmonization of fleet wide data. In order to profit from synergies between vessels, it is essential that maintenance data is administered from a central fleet wide data source. Implementing this information system harmonizes maintenance data and broadens the data structure to durations and qualifications.

The interface between planned maintenance systems and this crewing system is a promising approach for a cohesive IT system that connects the on board data structures. Recording work hours with maintenance task specification would allow the automatic synchronisation between the PMS and scheduling and reduce maintenance administration.

BENEFITS OF INTERDISCIPLINARY MAINTENANCE SCHEDULING:

- SIMPLIFICATION OF MAINTENANCE SCHEDULING PROCESS
- MORE RELIABLE AND COST-EFFICIENT MAINTENANCE
- FLEXIBILITY THROUGH SCHEDULES ON THE FLY
- IMPLEMENTATION OF CONDITION-BASED MAINTENANCE
- QUANTIFICATION OF CORRELATION BETWEEN MAINTENANCE, OPERATION AND CREWING
- DECISION SUPPORT FOR ANALYZING MAINTENANCE STRATEGIES
- HARMONIZATION OF MAINTENANCE DATA WITH LINK TO CREWING
- ADVANCES TOWARDS COHESIVE IT INFRASTRUCTURE ON BOARD
- MAINTENANCE PRIORITIZATION

The Unit Ship and Information Management at Fraunhofer CML develops decision support solutions for the maritime industry, for example SCEDAS®.

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