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Implementing Fleet Digitalization: Systems, applications and lessons learned.

Digitalization & Connectivity

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ABSTRACT

In 2019 the shipping company Euronav NV, commenced the implementation of a new, fleet-wide fast data acquisition , transfer and analysis, end-to-end system named FAST (Fleet Automatic Statistics & Tracking) which was principally based on the experience from a previous system FDM (Fleet Data Management) already used on several vessels since 2014.

The new system FAST would be able to transmit more than 500 parameters per vessel, with parameter specific data-rate optimization. Of these parameters approximately 12% are related to the vessel, 12% to the engine, 38% to the auxiliaries, 34% to the cargo and 4% to the bunker.

The specification was to serve the current and the future needs of the company for a modern monitoring, planning and optimization solution. The data collection, transmission and data residence facilities were contracted to specialist vendors. The data handling procedures for the high data-rate telemetry enabled by the FAST system were specified in-house, so that data can be best used by the downstream connected applications, allowing specific vessel by vessel analysis and fleet-wide overview and reporting at various levels. In the specially developed FDQM (Fleet Data Quality Management) system by the company Propulsion Analytics, the filtering involves not only boundaries, limits and statistics but also engineering process functions linking data parameters and related rulesets, to arrive at optimum validation of incoming data.

The paper describes the challenges in specification, the cooperation with specialist external contributors and vendors, the matching of vessels scheduling with staggered onboard data acquisition installations, and the various applications for decision support. With FAST, the decision support systems already present in the shipping company can be fed with high quality validated data, allowing more dependable analysis. The paper describes the experiences from the initial operation of the FAST system, from data acquisition to data filtering, and the usage of specialist applications for engine and vessel overall performance management and decision support advise.

1 INTRODUCTION

Digital transformation and the route towards connected entities in shipping is considered to lead to benefits of improved efficiency, energy economy, increased reliability, and emissions compliance. However, the retrofit of existing vessels, shore offices and other infrastructure with digital tools and analysis is rather challenging. Although the usage of data can enhance decision-making consistency, the increasing volume of data can be complex to manage [1],[2].

Crude oil shipping company Euronav invested heavily in digital transformation, by developing a central platform fed by IoT data from vessels. The solution is used to gain insights, lower operational costs and decrease fuel consumption - and therefore the organization's carbon footprint. Euronav decided to pioneer digital transformation using smart IoT technology. The goals include: further improving safety and environmental protection, increasing energy savings of the ships, reducing fuel consumption and carbon footprint, saving on vessel Operational Expenses (OPEX), improving collaboration and overall efficiency, and designing a path to Zero Emission targets by 2050.

The process for developing or acquiring digital products in a shipping company is quite long. The ROI is often unclear, since many vendors oversell their capabilities. Selection of vendors for specialist apps is challenging. Traditional large vendors are often preferred over smaller, which however may have higher agility and more advanced solutions.

Euronav has its own IT Innovation team that, with the support of carefully selected external partners, strives for excellence and top-notch innovative solutions. In recent years, several related projects were launched within the organization, both onboard the vessels and in the Euronav offices. The challenge involved creating an IoT platform that would run both on the vessels and in the cloud.

2 THE FAST PLATFORM

The Fleet Automatic Statistics and Tracking "FAST" is an ambitious and innovative digitalization project. It enables Euronav to take the next step towards improved fleet performance and fuel efficiency by utilizing real-time sensor data and improving communication and collaboration between ships and shore. FAST is a centralized, cloud-based platform integrated across vessels and shore offices of Euronav, receiving on board sensor data and instantly showing the condition and performance of vessels to teams at sea and on shore. The sensor data and resulting analytics aim to improve efficiency, enable more collaboration between vessel and shore, reduce operational costs and increase energy savings.

The teams can validate the data where needed, access raw data for deeper analysis, and combine this with additional information and events for a further enriched view, into more data-driven decision making.

The existing fleet data collection infrastructure before the FAST deployment, was characterized by a high diversity of legacy data collection systems, with issues of data availability; 60% of the vessels had an Endress+Hauser Memograph online data collection system which had served well for several years, but was operating at full capacity, while the new requirements were for at least 5-fold higher number of data streams.

For the FAST platform to work, the vessels needed to be digitally standardized. This involved new data collectors, an extension of the number of sensors on board, new IT infrastructure and cybersecurity.

On completion of the project, the FAST platform will provide:

- Real time fleet overview.
- Historical data.
- Multiple dashboards.
- Smart alerts and notifications.
- Improved (smart) onboard reporting.
- Optimization modules.

The platform was developed by a large team with a wide variety of competencies, consisting of Euronav's Fleet IT working together with Euronav's technical, HSQE and operations departments, as well as external IT partners companies that are experts in their field, as shown in Figure 1.

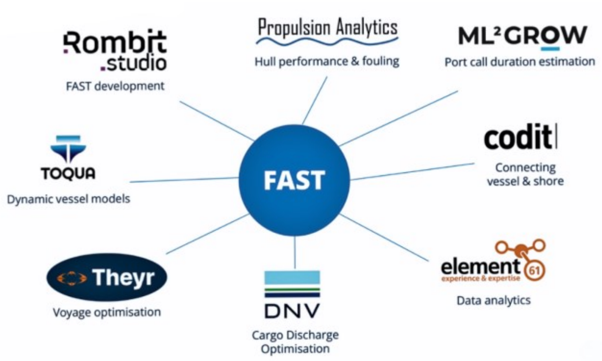

Figure 1. External partners of Euronav in building the FAST platform

The platform can instantly analyze the condition and performance of the vessel, such as fuel consumption, and show it to personnel both on- and offshore. Additionally, onboard engineers can add events and additional information to the data in order to enrich it. Sensor (raw) data is preserved for further analysis when needed.

3 DATA ACQUISITION, TRANSFER & STORAGE

It became clear early on that the collection of real-time, reliable sensor data was key to the project. Euronav was already making use of the Microsoft Azure cloud platform. Codit was chosen as a partner for the IoT development, connecting vessel and shore. The vessel's data goes through a central "data collector" onboard, which transforms, stores, and publishes the data to the cloud, using Microsoft Azure IoT Edge. The solution is designed with a microservices architecture, which means that it consists of multiple components that are self-contained and can be deployed separately. On the vessel, Codit uses a lightweight Kubernetes cluster to orchestrate the containers that are deployed there. Azure Arc is used to establish a central management plane for all the Kubernetes clusters. The next step is to get container images from ship to shore and back, which can be quite a challenge.

Although vessels are connected to the Internet 95% of the time, that does not say anything about connection quality. Communication with ships in oceans across the globe can suffer from poor connectivity, high network latency and connection drop-outs. Therefore, the solution had to be robust enough to allow for intelligent data exchange between vessels and shore. Euronav had already accelerated the roll-out of new Iridium Certus fleet antennas. These provide a constant flow of data from the vessel to shore locations (Figure 2).

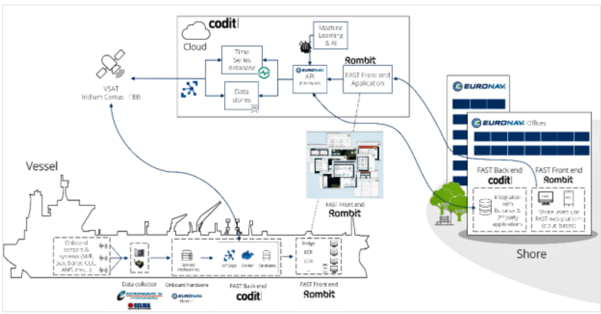

Figure 2. Linking ship-to-shore in the FAST platform

The data ends up in Euronav's FAST platform for processing. Data processing involves data cleaning, noise filtering, human error detection, sensor fault diagnosis, so that the subsequent analysis can operate on "clean, error-free" data.

4 DATA QUALITY MANAGEMENT

Sensor diagnostics is the assessment of good performance and the detection, isolation, and identification of faults in sensors. This must be independent from any variations of parameters in the process, since the sensor is the first interface between the data acquisition system and the process. Statistical tests with outliers and min/max may eliminate bad data and detect major deviations. However, it is imperative to also detect and identify "small" faults of sensors, like bias (offset) drift or precision degradation. Such "small" faults may allow poor data to encroach and pollute the dataset, thus influencing the subsequent analysis.

In general, sensor validation procedures are important because they are improving information accuracy and reliability, and enhance the decision-making processes and tools, resulting in higher availability of the fleet and reduced maintenance costs.

Several sensors in each vessel are transmitting data via the FAST system. At the deployment phase, the list extends to ~550 signals. An approximate percentage breakdown in terms of system is as follows:

- Vessel 12%
- Engine 12%
- Bunker 4%
- Auxiliaries 38%
- Cargo 34%

During 2021, Propulsion Analytics (PA) developed for Euronav a software platform to evaluate measurement quality, named Fleet Data Quality Management (FDQM) linked to the FAST telemetry system.

FDQM uses smart data evaluation for immediate identification and alerting of sensor errors, overview and evaluation of fleet data quality and tagging of data quality for subsequent use. This results in reduction of storage and downstream analysis cost.

In FDQM the sensor validation is divided into three steps. In the first step, the FDQM platform checks if a sensor is operational and records a value for the specific parameter and time interval. In the second step, FDQM is applying a set of algorithms to validate the recordings and to detect if the sensor is biased or out of calibration. In the third step, if FDQM has identified that the recorded value is not correct, an additional set of algorithms is executed in order to correctly predict a "substitute" value, when this is possible.

Figure 3 presents a layout architecture of the FDQM evaluation platform connected to FAST.

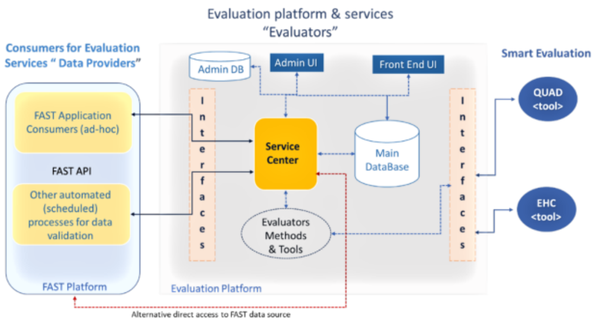

Figure 3. Layout of the FDQM system

Four different classes of methods are used to evaluate signal completeness and quality KPIs:

- Initial validation using vessel specific signal limits (min/max) and outliers' detection,
- Statistical deviations and statistical quality control,
- Engineering analytical rulesets,
- ML outlier detection and data imputation

The results from all different levels of data processing and analysis are presented through a set of views in a Web User Interface with plotting, trending, alerting, and reporting facilities.

- an overview for the whole fleet, a dashboard providing high-level information about sensor health, status, and metrics.
- a vessel view with all specific details of data quality per vessel, including a drill down level specific measurement points and sensors as well as detected issues.
- a dedicated view for the administrator to control the platform, the number of the monitored vessels and the signals and validation methods used.

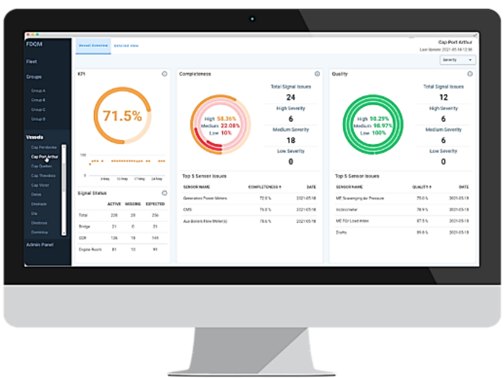

Figure 4. FDQM vessel signal status overview

The migration from the previous Euronav telemetry system (FDM) to the new one (FAST), involved the conversion of the previous timeseries data streams to the newer format. The migration process involved exporting data from the old database, transforming it into the appropriate format for the new data structure and format, and then storing them into the data storage (data lake). An overall FAST flowchart is shown in Figure 5.

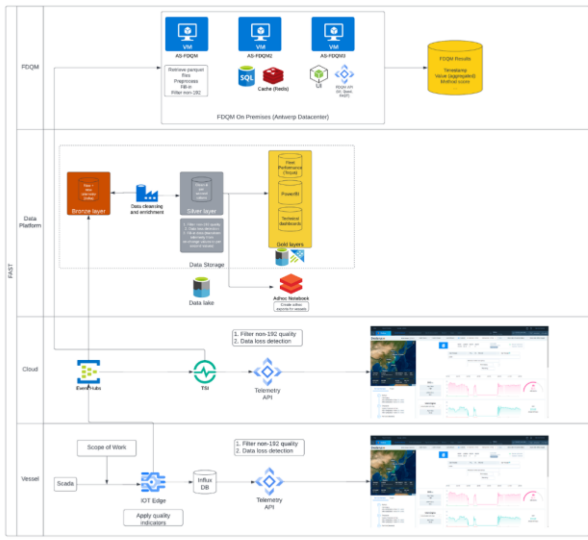

Figure 5. FAST flowchart

5 DECISION SUPPORT TOOLS

Once the data infrastructure system is in place, it is possible to feed various decision support applications both onboard and ashore with operational data. Several of these tools are specialized applications, which may be interrelated, exchanging information, and linked to the company's ERP. Such tools are presented in Table 1. Eventually, integration of such applications may take place to form a "fleet operation center" in the shipping company.

Table 1. Decision support systems/ fleet operation

Operations support systems
• Demurrage forecaster • Port-cost estimator • Chartering Assistant • Off-hire assistant
Voyage Performance Management
• Voyage speed optimization • Weather routing-safety & efficiency • Trim/Drift/Autopilot optimization • Voyage Emissions assessment
Condition Based Surface Maintenance (CBSM)
• Hull/Propeller condition assessment • Vessel performance evaluation, prognostics • Hull/Propeller roughness management-when/where

Ship System Management
• Efficiency-Emission-Economy 3E optimization
• Cargo Heating/Boiler optimization
• Energy improvement retrofit device assessment
Engine & Machinery health
• Maintenance/Repair when/where
• CBM/PMS
• Spares management/Replenishment assistant
• Main engine performance evaluation
• A/E performance evaluation & Optimization

Many of the specialist applications can be complex, with elaborate user-interfaces to support a wide-spectrum of potential users. Often a human expert service is provided by specialist vendors to accompany the software application. Some of the decision support applications at Euronav are detailed below.

5.1 Vessel Performance evaluation

Vessel performance evaluation is a primary concern of shipping companies. The needs of a shipping company in vessel performance evaluation are summarized in Figure 6.

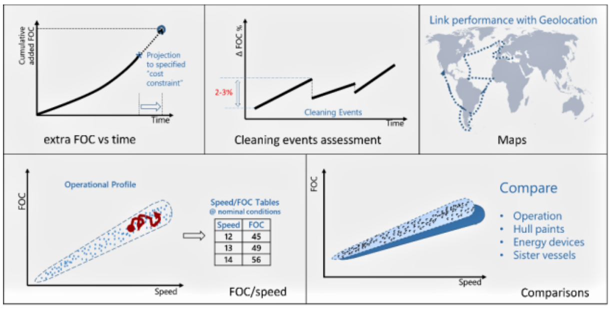

Figure 6. Features, vessel performance evaluation

In general terms, the vessel performance can be quantified as the cost of obtaining a certain vessel speed. As shown in Figure 7, this cost shall increase if the vessel temporarily experiences heavy weather leading to increased resistance, hence increased power, and fuel demand. It will also increase over time due to the hull fouling, which will result in increased resistance, and hence increased power demand to obtain the same speed.

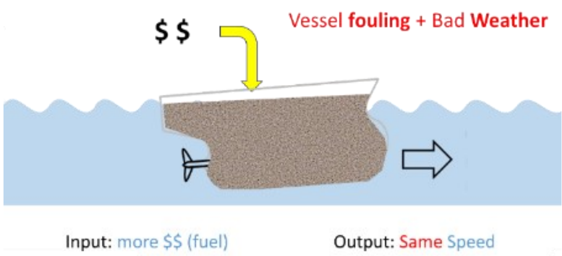

Figure 7 Effects of vessel hull fouling and bad weather

Occasionally some increased fuel consumption may also be due to engine underperformance, where the needed power is obtained with lower efficiency. To be able to evaluate the performance, several parameter values must be measured using sensors and data acquisition systems. Any such measurements will inevitably have some uncertainties. In general, there are "easy" measurements such as pressure, temperature, length, time, and "difficult" measurements such as torque, fuel mass flow, vessel speed through water. The latter measurements need careful validation, before being used in any evaluation.

Since the pursued change in resistance due to fouling is a slowly changing parameter over time (at the end of a 12-month period this fouling power penalty may develop into 3-5% of the total resistance value), it is evident that utmost accuracy in measurements and estimates must be concurrently ensured, to have any meaningful results.

A widely used method for fouling penalty estimation is comparing measured values of ship power to the expected power at same condition, obtained by adding up predictions from models of component resistance (skin friction, wave-making, wind etc.) and then from the comparison residuals to infer the fouling power penalty. With this approach, the residual is the (small) difference of two (large) values of expected power and measured power, both of which may have errors, the former from all the errors in the various models, the latter from any torquemeter inaccuracies. Since the pursued residual value can be of the same order of magnitude as the cumulative errors, Propulsion Analytics considers this method inaccurate for certain use cases.

Continuous vessel operation measurements and telemetry can readily provide over time large amounts of data. Propulsion Analytics' QUAD vessel performance application firstly cleans such data then feeds clean and validated data into machine learning algorithms for accurate vessel performance profiling. QUAD can then provide continuous up-to-date fuel consumption predictions for different combinations of weather, vessel speed, loading, trim etc., fact-based hull and propeller fouling condition assessment, cleaning decision support and ex-post evaluation of cleaning success and hull/propeller efficiency improvement retrofit evaluations. A patented procedure has been formulated to discriminate propeller fouling [3]. QUAD as a standalone application can link with any third-party platform which supports continuous telemetry data.

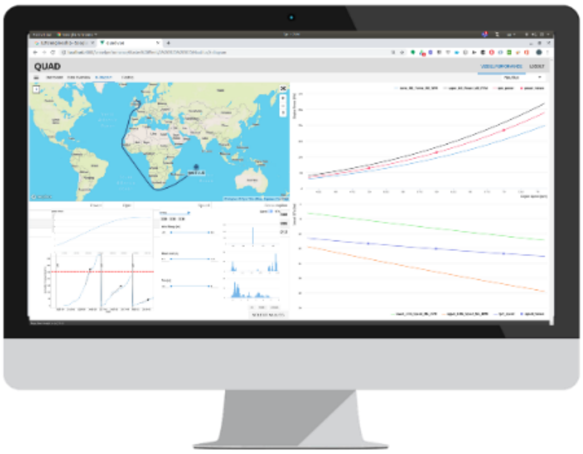

Figure 8. QUAD monitor

QUAD was customized for Euronav using as input continuous data from the FAST system. The gradual increase of the power penalty due to fouling over time, as well as any power and fuel consumption changes resulting from cleaning or other events can then be determined, as shown in Figure 9.

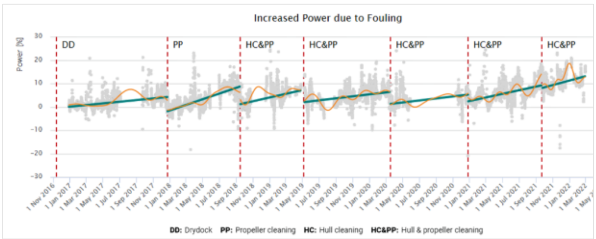

Figure 9. Fouling history between cleaning events

Vessel performance detailed evaluation based on actual operational data allows moving from planned fixed-term cleaning events to adjustable hull and propeller cleaning events based on the fouling condition.

Using FAST data, QUAD has also been employed for assessments and comparisons, as described in the examples below.

Hull paint evaluation: Three sister vessels with different hull coating schemes were compared to evaluate premium and silicone versus basic antifouling paints. It was established that torque meter operational issues are often faced – this is critical for the analysis. Operating profiles and idle periods were considered in the analysis. In one case 8-10% fuel savings after 60 months in service was estimated. It was further found that a self-polishing antifouling can be very good until the first hull cleaning event, subsequently exhibiting deterioration.

Vessel fouling and cleaning: A group of 6 vessels was examined. Three vessels had a recent cleaning event (drydocking, hull brushing or propeller polishing). In two of these vessels, the recent events were evaluated as successful, resulting in no or very small overconsumption compared to the vessel after a drydock. In one vessel, the cleaning event (propeller polishing) was deemed unnecessary since it did not affect consumption. The other 3 vessels had cleaning events 9 months in the past or more and exhibited substantial fouling, resulting in 4 to 6 tonnes per day added fuel consumption. A cleaning event was urged at the earliest opportunity.

5.2 Engine Performance Evaluation

A set of engine performance related tools of Propulsion Analytics were customised for Euronav.

An engine performance recording "smart form" was produced, to be used by the crew onboard for main and auxiliary engine data collection and submission to the shore office. The form has mechanisms to avoid clerical errors in any manual input, rulesets to avoid unrealistic input, checking for incomplete data fields and functions for auto-fill data.

Furter, an Engine Data Platform (EDP) was developed as a shore office application that receives and stores all engine related data for all vessels, with reporting and charting functions. The EDP system can interface with the Engine Hyper Cube® digital twin engine performance analysis application, described below.

5.2.1 Engine Hyper Cube®

The Engine Hyper Cube® (EHC) is an engine performance assessment application of Propulsion Analytics, installed in several vessels of Euronav for main and auxiliary engines. It includes a "digital twin" based on a thermodynamic model, tuned to be an exact replica of the actual engine in operation [4].

The Engine Hyper Cube® software, by comparing engine measurement data collected from the vessels to the digital twin, can provide a detailed engine status assessment, diagnostics, prognostics and optimization recommendations (Figure 10).

The EHC can be used with data input ranging from field records (performance reports with manual entry) to fully automated telemetry monitoring.

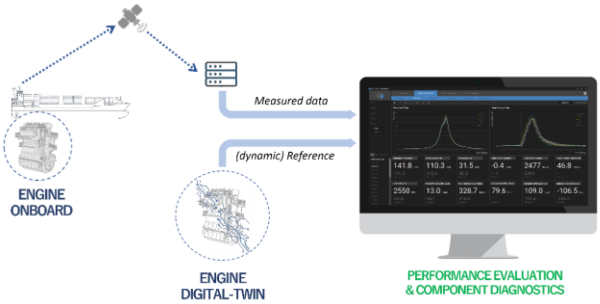

Figure 10. From engine data to performance evaluation using EHC.

For a group of 20 vessels over a period of 36 months, the following statistics emerge:

- On average, there were three engine related issues per vessel per year. 75% of occurrences were engine faults, 25% were sensor issues.
- From the engine faults 35% were Cylinder compression issues, 40% were injection and combustion issues, 10% turbocharger issues and 15% other issues.

In certain cases, with detected faults the engine load level had to be considered. Then a connection with QUAD was established. Since QUAD is fed with continuous FAST data, the engine load history and any unusual operating conditions could be revealed.

Combining Engine Hyper Cube® with the QUAD application and using the "engine as sensor," resolves the fundamental problem of torque measurement uncertainty, by using thermodynamic torque estimation from the Engine Hyper Cube® digital twin. (Figure 11).

Figure 11. EHC UI- engine performance details

This independent torque estimation by Engine Hyper Cube® can validate any measurements, can supplement any missing or erroneous values, and augment the recorded torque data series. The application can further provide thermodynamic estimation of fuel consumption, which can validate related measurements.

Warnings and recommendations of the application were regularly acted upon by Euronav, with substantial benefit the good engine availability. Early warning of developing faults also leads to operational benefits in planning maintenance at a convenient time. Further, in certain cases of reported good performance, prolonging maintenance intervals may be considered.

6 LESSONS LEARNED

6.1 Digitalization

The digitalization end-to-end, vessel to office is a complex project, with several independent interacting elements in need of integration. It involves many stakeholders and must be designed to meet their needs. It is invariably limited by time, budget, and resources. However, these end conditions are often not fully met and need to be protracted. Due to the complexity and the new or unproven technology and applications to be used, the complete specification cannot readily be completed from the start and may have to be revised. The overall spec should not be just an assortment of offerings and claims by various vendors, which may result in contradictions.

Technology moves fast and with the inevitable delays in installations and integration, there is always a danger that some systems may not be up-to-date when the whole project is finally completed and in need of revision before even starting to work.

The introduction of digital tools in existing infrastructure of shipping companies has several difficulties. Some companies resist outsourcing in what they consider core competency and a source of competitive advantage. With interlinked specialist applications for a wide spectrum of activities, integration becomes increasingly challenging. Ownership and accountability in a complex chain is also a challenge since different parties are responsible for individual segments. A balance must be found between the compulsion to build a team within the company and make everything arguably more cheaply in-house, or to use a one-stop-shop external vendor, or to integrate offerings from several external vendors.

6.2 End-to-end solution

Euronav chose to build its own end-to-end solution in partnership with different vendors for the various subsystems: sensor data collection, storage onboard and upload to cloud, design and development of applications. On the one side this brings full flexibility to build the solution as best suited for its needs; on the other hand, it increases the complexity of project management and interconnection of apps.

Complexity also arises from the storage, management and sharing of the large amount of data collected from the vessels. Euronav developed a Data Platform for this purpose, based on Microsoft Azure. This development entailed the creation of several data validation layers. Each of the data layers serves a different purpose, either for a general requirement (e.g., front-end web pages) or for specific business use cases (sharing data with a voyage optimization AI platform for calculating optimal routes).

Optimization is key for the data management as there are multiple different tools and storage options on Azure, so it is important to pick the proper one for each case, otherwise either performance will deteriorate or costs will escalate. Euronav uses external expertise for this part as well.

6.3 Retrofitting digital tools

Retrofitting of vessels with digital tools must be planned to fit with the schedule of vessels and probably to coincide with drydockings. This may increase the timescale of completion of the whole project. During that period there may be market issues, key personnel replacement, strategic priority changes where the initial goals, visions and perceived advantages may be questioned. The complex interrelated systems are difficult to benchmark, more so than the individual applications. Different onboard installations on various vessels may pose individual problems and lead to further delays.

Covid19 was a significant delaying factor in the installation of Euronav's Data Acquisition System (DAS), as physical attendance is necessary for carrying out the installation of the sensors and all required hardware by certified and experienced technicians. In normal times this would have been easily facilitated during the dry-docks in China, however China was exceedingly strict with their Covid19 restrictions thus making it impossible for the installation crews to carry out their task.

On the other hand, it is also difficult to find port calls or short voyages of the exact right duration (7-8 days). Shorter periods mean the work may not be completed and then a re-attendance will be required, whereas longer periods mean that the technicians would be tied up idling onboard.

Another area which has been a cause of delays is the unlocking of AMS and/or CMS. These systems both offer many critical signals which are otherwise difficult to collect onboard. However, in order to connect to these systems and retrieve the data, complex procedures are required and sometimes significant cost.

6.4 Data management

FAST and the linked shore office applications had to face all the above issues, despite Euronav's experience with the previous already installed onboard system FDM. Signal quality and data rate affect the data storage arrangements. Once the FAST system was operational it became evident that the data acquisition frequency of some of the ~550 signals had to be revised. Certain parameter values were required at higher frequency, some at lower than specified. Filtering and data quality evaluation was performed by the specially developed application FDQM.

6.5 Applications

Specialist applications are complex and often difficult to evaluate. Pilot installation is the usual procedure to test a new application in a shipping company, but these pilots require time and human resources from the end-user not normally earmarked beforehand. The deployment of applications and tools in the new FAST platform encountered several issues, as in the examples below:

- The migration of legacy time-series data from the previous telemetry system FDM of Euronav to the new FAST system was challenging due to the sheer volume of a several years data from many vessels and the need to preserve the integrity of the information.

- Calculations of speed-consumption tables in QUAD exhibited peculiar trends in some cases. This was found to be due to few available data or poor data quality in some operating areas, biasing the analytics algorithms. This was alleviated by using combinations of alternative algorithms, updating the application.

- Slow response of the EDP and QUAD applications was observed in multiple queries. In the case of EDP the design had to be revised to cope with the simultaneous usage for all the fleet. In QUAD it was resolved by optimizing the data input to the analytics algorithms.

6.6 End user involvement

Evaluation of the end-to-end system and user involvement is not always accomplished swiftly, since there may be opposition for several reasons. Tangible improvements may be slow to materialize. Occasionally the end-users are reluctant to accept changes in their way of working or fear that people may be made redundant.

As the project has progressed, Masters and shore staff have suggested many additional functionalities which offer distinct, traceable benefits which Euronav intends to incorporate into the system. In addition, Euronav plans to further develop on "Voyage Optimisation" projects, fuel and lube oil consumption monitoring and technical performance dashboards (KPI's) with a clear return on investment over the next few years.

7 CONCLUSIONS

Developments in sensors, telemetry, computers, and control have enabled marine technology initiatives such as the Unmanned Machinery Spaces (UMS) in the 70's, the Ship of the Future and Electronic engines in the 90's, Digitalisation at present and Autonomous vessels in the near future. All these developments aim towards economic gains, along with improvements in efficiency and safety, plus sustainability and environmental benefits.

The FAST platform (Fleet Automatic Statistics & Tracking) gives Euronav a competitive advantage in the shipping industry. Moving forward, they will certainly build on their current experience in data analytics. Teams in Antwerp and Athens are developing new dashboards, reports, and insights. Moreover, with a better line of communication between vessel and shore, there is less need for captains to write time-consuming reports, allowing them to focus on their core task of ship management. Other results of the data collection, analysis and visualization are increased safety, environmental protection performance, and lower Operational Expenses. There are several other benefits, such as predictive maintenance, shorter waiting times at the quay and reduced claims. The overall benefits of FAST cannot be readily monetized at this time, since the platform is still in the deployment stage. An important expected result is a reduction in the use of fuel. For each 1% of reduced fuel consumption fleetwide for Euronav (within the expected benefits using the FAST platform) leads yearly to at least 6 Million USD savings and 30k tons reduced CO_2 emissions, towards the organization's goal of achieving zero emissions by 2050.

8 DEFINITIONS, ACRONYMS, ABBREVIATIONS

3E: Efficiency, Economy, Emissions
A/E: Auxiliary Engine
AMS: Alarm Monitoring System
CBM: Condition Based Maintenance
CBSM: Condition Based Surface Maintenance
CMS: Cargo Monitoring System
DAS: Data Acquisition System
DD: Dry Docking
EHC: Engine Hyper Cube®
ERP: Enterprise Resource Planning
FAST: Fleet Automatic Statistics and Tracking
FDQM: Fleet Data Quality Management
FDM: Fleet Data Management
HSQE: Health, Safety, Quality, Environment
IoT: Internet of Things
KPI: Key Performance Indicator
OPEX: Operational Expenses
PMS: Planned Maintenance System
PP: Propeller Polishing
ROI: Return on Investment
UMS: Unmanned Machinery Space

9 ACKNOWLEDGMENTS

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