The rise of asset performance management in the marine industry - merits and definitions

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SYNOPSIS

Digitalization is transforming the world and opening up new opportunities in industrial sectors, including ship systems, by unlocking real value from data. Moving from vision to tangible value, these digitalization programs are driving real impacts both on land and at sea. We're now seeing plant and energy systems fully connected to the cloud, improving safety, productivity, accessibility, sustainability and situational awareness, bringing real value to operators.

No matter how stringent the rules governing the design, testing and integration of ship's equipment and systems, maintenance, repair of equipment and avoidance of downtime always present a challenge and therefore it is a high priority for any ship's crew to continue operation, extend the life of valuable assets, and enhance performance and mission readiness. Accessing systems information from any location, automatic diagnosis would provide quicker command and control of intelligent devices. The Internet allows real-time access anywhere on the globe through open protocols.

Similarly, unplanned downtime is one of the key cost drivers in ship systems; an asset performance management solution allows the shift from traditional calendar-based maintenance to predictive maintenance, significantly reducing unplanned downtime and maintenance costs, thus, allowing operators to plan corrective maintenance around operations to further reduce unplanned downtime. As digitalisation is becoming an integral part of the maritime sector, more and more operators can benefit from its use.

Monitoring all assets of the power and propulsion systems for data collection and analytics is available as a standard feature and provides a holistic view of the plant performance. Modelling of products and systems has been around for decades, but it is only in recent years that the digital twin has captured imagination and come into the mainstream. This allows ship equipment and systems to be compared to their perfectly healthy digital twins –digital replicas built on validated data models plus normal operating profile. By spotting data variations, the software can simulate how the ship will perform without needing to test it in the real world, will automatically indicate future potential electrical or mechanical faults and inform the operator in real time what to fix or what is broken or warns to take immediate actions to instantly adjust parameters to avoid overloading the equipment and ensure their peak performance. Studies completed to date have resulted in considerable reduction in operational expenditures across the targeted equipment.

Having a digital twin can also help capture knowledge and reuse it in the design process, train operators and avoid repeated pitfalls to ensure operations are carried out with improved efficiency. An example of this can be optimizing fuel consumption and reducing emissions for a particular voyage, by including external factors such as wind, current and weather conditions.

This paper will cover methods adopted for asset performance management with advanced analytics to detect off-standard behaviour to enhance predictive capabilities for equipment/system and ultimately enable predictive maintenance, reduce unplanned downtime and allow personnel on-board to focus their resources on maintenance activities that are truly needed and effective.

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1. Introduction

The Marine industry faces substantial pressure as global trade growth has decelerated, and commodity prices have declined. The ensuing struggle for market share underscores the need for greater efficiency in the commercial marine sector, both competitively and to meet environmental regulations. Similarly for navies, pressure on budgets and a need to stay on mission means there is an increased drive for efficiency.

One of the answers to these challenges lies in innovation. A new generation of digital technological advances in Asset Performance Management (APM) can bring substantial benefits to the Marine sector.

Combining data with smart analytics and industry knowledge can deliver better insights on asset condition and performance.

APM can help to mitigate the challenges of cost and availability of an experienced workforce by allowing experienced operators in a centralised location to monitor and remotely support multiple assets, thereby making it easier for teams to share, store and access information.

With these conditions in place, APM offers an unprecedented opportunity to transform the Marine industry. APM can reduce non-productive time, improve performance reliability, cut fuel consumption, improve operational and mission efficiency for both individual assets and entire fleets, optimise fleet and logistics planning and routing and accelerate the development of green vessels.

Organisational transformation is key to implementing digital transformation, as the need to adopt and change behaviours is critical to the success and impact of APM solutions. Technology is not always the challenge – often people and processes are the biggest challenge an organisation faces when adopting digital technologies.

APM solutions use either Physics Based Analytics (PBA) or Similarity Based Modelling (SBM), or a combination of both. Combining these with machine learning provides powerful insights into asset health and performance.

Another commonly used term is Digital Twin (DT), which refers to a digital representation of a real asset. DTs can be used in early stages of design to model the expected behaviour of an asset in the real world, and gradually enhanced over the development and testing cycle, until finally used as the "healthy" blueprint to compare against once the asset is in operation. A DT can be created using PBA or SBM, or both and is considered under the umbrella of an APM solution.

2. Ship Power & Propulsion Systems

The diverse operational profiles of modern vessels (naval or commercial) leads to a trade-off between efficiency and adaptability and have led to a growing variety of power and propulsion architectures (Doerry and Fireman, 2006):

- Full electric power and propulsion, mechanical propulsion, or a combination of both, forming a hybrid system.
- Power generation with combustion engines, supplemented by energy storage or a combination of both.
- AC or DC electrical distribution.

The selection and design of ship propulsion systems is not the topic of this paper, suffice to say that its process can be complex and has many key points to consider.

The increasing ship sizes and use of higher electric-consuming loads have produced a requirement for propulsion and generating plants of significantly larger capacity than has previously been necessary. Increased vessel safety, higher system flexibility, lower operating and through-life costs, enhanced availability, reliability, maintainability and lower emissions are just a few of key performance indicators at the forefront of ships assets evaluation.

In addition to hardware, ship systems come complete with complex automation and controls that contribute to efficient and safe vessel operations. Such automation and safety systems mainly consist of:

- Power management

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- Vessel alarm and monitoring systems
- Propulsion and auxiliary control systems
- Dynamic positioning systems
- Ballast, cargo monitoring and control system, HVAC (heating, ventilation, air conditioning)
- Emergency, process shut down, fire & gas detection, and other monitoring systems.

Automation system architectures comprise complete integrated control, reliable with accurate functions, preferably using open design, having high redundancy from collection of input/output signals through individual sensors, modules to operator stations, communication links, and secure power supplies communication systems.

Controllers communicate easily with each other and with other party's products or equipment and need fully to comply with international standards and protocols. The whole automation kit is not just a hardware and software module but is a full solution that aims to ensure stable and optimal operation of the ship power, propulsion and auxiliaries. It provides a powerful integrated suite for:

- Configuration, programming, debugging, monitoring, and maintaining the integrated systems, locally or remotely.
- Process information, permissive management, alarm/fault display, historical data trending, and logging to operators enable tight control and monitoring of processes to ensure the highest possible quality and productivity
- Interface to various systems, subsystems, products data management and tracking
- Data collection and quality tracking
- Diagnostic systems, equipment status and process alarms

Control and automation systems therefore provide a valuable backbone on the vessel for communication, data and connectivity.

3. Data Monitoring and Analytics – Scope & Principles

There are a number of system related topics when considering asset management and performance.

3.1 Baselining system performance

Ships' power and propulsion systems represent one of the most important investments on a vessel and require great engineering skills and resources to design, manufacture, operate, control and maintain. Indeed, they are a critical enabler of ships' missions and it makes sense they are the focus of asset performance management (APM).

Reliability and availability of such systems are paramount to avoid loss of propulsion and downtime. It is therefore of prime importance to monitor key equipment, sub-systems and systems parameters and operating conditions and have such *information* (not just data) readily available and easily interpreted.

Condition monitoring is based on the notion of change; that change takes time and may indicate deterioration in condition, hence raising the likelihood of a fault developing. The challenging task then is to identify the cause of change and determine whether it constitutes a threat to the continued reliable operation. If the change is caused by a developing fault, it is highly desirable to predict how long it will be before the fault reaches critical proportions, possibly leading to a catastrophic failure. Obviously, the earlier a developing fault is detected, the more effective the operational intervention can become. Benefits of early detection are manifold, ranging from preventing costly repairs and loss of power generation, propulsion or even ship duty caused by a major breakdown to being able to sustain critically important services without interruption. Condition monitoring should take necessary data measurements and, through analysis, extract a detection and diagnosis of equipment or system. A condition can then be inferred, in minimum time, giving a clear indication of incipient failure modes.

With such objectives, a condition monitoring scheme in place would detect the electric or mechanical change, identify the cause of change (diagnosis), and predict what the state of the equipment, subsystem and system will be in the foreseeable future (prognosis). Most data is available at different levels, monitored by automation systems (Tavner, 2007).

3.2 System analytics techniques

If we take electrical machines (generators or motors), they have received intense mechanical, electrical, electromagnetics and control research interest for more than 30 years (Göl and Nafalski, 2007) . However, condition monitoring of electrical machines does not appear to have received the same attention as other large mechanical machinery, probably due to the gained confidence that not much can go wrong with electrical

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machines. Yet, electrical machines can suffer from a range of operational faults. These could include both mechanical and electrical nature such as bearing defects, shaft fractures, fan blade damage, rotor bar or poles, temperature rise (bearing/stator temperature), winding short circuits, unbalanced magnetic pull, insulation degradation and conductor fractures, electrical (voltage/current total harmonic distortion (THD), sequence voltage/current harmonics, energy usage)…etc.

Electrical machine monitoring parameters have some of their sensors already installed from manufacture and are monitored either locally or remotely. However, with the addition of PBA techniques such as Electrical Signature Analysis (ESA), the ability to identify developing faults is possible. Traditionally, failures in rotating machines were detected using vibration sensors. However, vibration sensors can only detect mechanical failure, and not common electrical failure issues such as insulation degradation in high and medium-voltage motors.

ESA is not a new technique, although it is a technique that industry has not exploited to its full potential until recently. The ESA algorithms monitor the stator voltage and current of rotating machines and capture it in the form of a high frequency time series waveform. The time series data is then converted to the frequency domain by using Fast Fourier Transform (FFT) to closely monitor changes or unexpected signatures in the frequency domain (GE, 2019).

Through years of research, experience, deep understanding of the mechanisms of electrical machines, different algorithms have been developed that are capable of not only detecting a change in the frequency domain, but also identifying the specific failure mode that is developing.

Therefore, when looking at the frequency domain representation of the response of a system, the peaks will be at the frequency locations of maximum energy exchange and dissipation. If a physical system doesn't change over time, then its frequency domain should also remain constant. Changes would indicate a developing fault with the physical asset (Göl, 2007).

ESA can also be used in conjunction with vibration and temperature monitoring to drastically increase the range of potential failures that can be predicted well before they happen. Combining PBA with machine learning (ML) provides information on a far wider range of fault modes than temperature and vibration sensors can alone, and when used together, the range of potential failures that can be detected and advanced warning before failure are both extended even further, as illustrated in Figure 1.

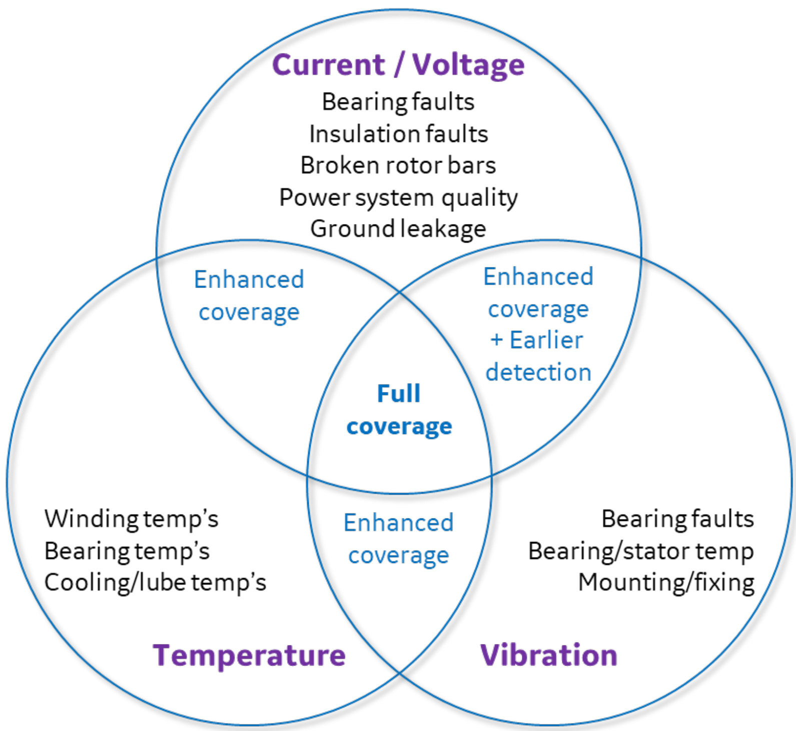

Figure 1 - Fault detection by sensor technology type

Another example would be variable frequency drives (VFD) which are equipped with comprehensive monitoring of health and operating condition, such as voltage, current limits, cooling system pressure, flow rate, major components' temperatures, and analytics developed to identify possible future issues and reports for the user. VFDs can be fitted with a software module providing access to high frequency measurements which can be used to perform PBA. Based on the PBA data from the VFD, the following insights can be derived:

- Major components (capacitors, inductors) estimated life
- Coolant permeation/leakage
- Pump pressure difference
- Power electronics analytics and power cycles.

4. Digital Twins

Use of Digital Twin (DT) analytics allows to continuously monitor equipment performance and detect degradation, which provides advanced warnings of potential failure, often early enough to recommend carrying out additional maintenance inspections or specific tasks.

This early warning may allow time to mobilise service engineers and order parts which can be critical at sea, especially in remote locations, or vessels that return to port infrequently. The early warning prevents un-planned downtime and associated loss of production/availability.

DT based analytics uses advanced, mathematically compact, modelling techniques to analyse data in real time with tolerance of faulty data.

DT analytics can use the existing instrumentation on any type of equipment or process, regardless of the equipment manufacturer. Second, it covers multiple, dynamic equipment operating modes on a serial, number- specific basis to personalize the analysis. Finally, its empirical modelling techniques use only historical operating data rather than detailed process or equipment engineering data.

DT analytics' approach is data driven. It creates an empirical model for the entire asset by looking at how each sensor works in correlation with others. The dynamic band is a result of not only that sensor's performance but how it relates to the other sensors as well. It accounts for ambient, load, and speed conditions. The dynamic band is very tight and able to catch subtle yet significant variances. It is the combination of the dynamic band and the correlation across multiple sensors that enables a clear picture of the health of the asset and system sensors and enables real-time predictive warnings.

5. Benefits of System-Level Asset Performance Management

5.1 Examples and data used throughout this paper are mostly related to commercial/ offshore vessels due to lack of available data for naval ships and occasionally sensitive data that cannot be disclosed. However, the general principles remain generally similar.Survivability

Survivability is a complex subject as it covers redundancy, high integrity, fault-tolerant systems, spatial separation, and manual backup systems for continuity of vital services during major disruptions.

APM prognostics with a corresponding capable protection scheme that can sense, isolate, and quickly compensate for major disruptions, can maximise system integrity, minimise interdependencies and tolerate simultaneous disturbances to both machinery and control systems. e.g. engine/generator sets, a switchboard section can be out of operation without major consequences to vessel operation, and part of the ship system can be operated thus giving a high degree of survivability, redundancy and flexibility of operation.

Tracking of parameters such as fuel and excitation vs power on the engines, harmonics vs load for various configurations on the switchboard, number of operations of circuit breakers on-load and off-load, etc, can all provide valuable insights into the health of the system.

The enhanced generator monitoring function can also take action by detecting and, if necessary, isolating a faulty generator from the power system, removing it before the fault fully develops, minimising the impact of the fault on the power system and mitigating the risk of blackout. In addition, the performance of each generator can be monitored to identify reductions in generator excitation performance or prime mover and governor performance.

5.2 Economics and emissions

With the tightening of budgets and legislation the maritime industry requires more efficient vessels to minimise operational costs with cleaner technologies that meet stringent environment regulations and reduce greenhouse gas

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emissions. The marine industry is responsible for about 2.5 percent of global greenhouse emissions. With pressure comes the opportunity to incentivize energy efficient measures, both design and operational (Simmonds, 2013, Benatmane, 2019).

Considering ship operation profiles provide a great insight about utilisation, this presents the opportunity to exercise various alternative measures to reduce fuel consumption, and hence carbon and sulphur emissions, in a cost-efficient way. Such exercises may include evaluating the feasibility to reduce port time, improving port facilities and technologies to maximise energy efficiency of the operations and voyage optimisation (including route planning) to reduce fuel consumption. Furthermore, analysis of current operating profiles for individual ships will allow for identification of how operations can be improved in a relatively short term to increase energy efficiency and reduce carbon emissions in a cost-effective way.

A significant amount of data is available and can be collected from the ship's systems to conduct analysis to look at fuel consumption speed, encountered weather and time spent operating in different weather in order to reduce energy footprint by optimising fuel consumption and reducing emissions.

Significant improvements in efficiency can be gained by changing the behaviour of the vessel operator by providing real-time insights into the current operating conditions of the system versus past similar operating conditions where less fuel was consumed. This would enable the operator to reconfigure the system to operate more efficiently without sacrificing integrity or performance, for example running additional engines when the load demand does not require it (while in transit). Engines operating at very low load are not only inefficient but can also have a detrimental effect on engine health, resulting in increased spend on maintenance and higher probability of failure.

Such a vessel optimisation solution can be used to provide:

- Real-time view of the vessel's operational state and its effects on fuel consumption
- Minimum number of generators to run at their optimum efficiency point
- Individual and total engine running hours to help reduce fuel consumption, maintenance costs and extend service intervals.

Operators can benefit from adjusting system configuration or speed, and fleet managers can monitor fuel strategy across individual vessels, fleet and operating scenarios, and even adapt vessel operator training.

The vessel optimisation solution is also capable of logging key data, that can be used for reporting, related to:

- Operational state of the vessel, including auto-detection of the current operating mode
- System setup
- Environmental conditions
- Vessel position and heading, and
- Fuel usage statistics (i.e. instantaneous and average values)

5.3 Operations & Process Optimisation

Optimisation of operations can be enhanced using SBM techniques by modelling operational *processes* to drive improvements in operating efficiency, consistency and predictability.

Ignoring a proven process would affect productivity, quality, reliability and in some cases safety. Detecting process variations is near impossible without data; however, combining data with knowledge from subject matter experts (SMEs), algorithms can be developed to achieve positive outcomes.

Operations optimisation methods can provide benefits in mission critical applications where data from systems can be analysed in real-time to automatically generate actionable insights. The insights are presented in stakeholder-specific dashboards for enhanced decisions by operations crews, and fleet or vessel managers onshore. The solution enhances operational efficiencies with an evolutionary approach:

Information – Derive process, detect deviations and enable drill-down

Intelligence – Identify process anomalies as well as sources of anomalies

Guidance – Predict potential anomalies and mitigate impact on mission or lifecycle.

As the solution insights get refined, the stakeholder decisions get better thereby enhancing operational efficiencies across each vessel which can be systemised across the fleet.

Having the ability to compare performance across multiple assets/sites can bring real value in identifying inefficiencies and variances in operation.

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5.4 Maintenance

Maintenance is still widely performed on calendar-based schedules. Some industries are moving away from schedule-based to usage-based, such as automotive, where your car is now intelligent enough to show when oil needs changing.

Traditional schedule-based maintenance typically covers assets designed to run at high loads for extended periods of time. Often in reality, equipment is operated at lighter loads than the design nominal; hence equipment is subject to less wear and needs less frequent maintenance.

Therefore, using data monitoring maintenance may be performed when it is actually required rather than on a specific date scheduled.

By creating "usage" models of assets, it is possible to use existing operational data to derive how intensively a piece of equipment has been utilized and use this to delay scheduled maintenance on equipment that has been lightly utilized.

Not only does this reduce spend in man-hours and parts on maintenance, it also provides the flexibility of performing maintenance around operations by providing a "window" of opportunity to extend the maintenance window.

PBA and SBM solutions should be used together with maintenance optimisation to act as a "safety net" to ensure no detrimental effect of prolonging maintenance intervals.

6. Examples of Asset Performance Management in Use

The journey from current intuition-based decision making to true data decision making has three distinct phases:

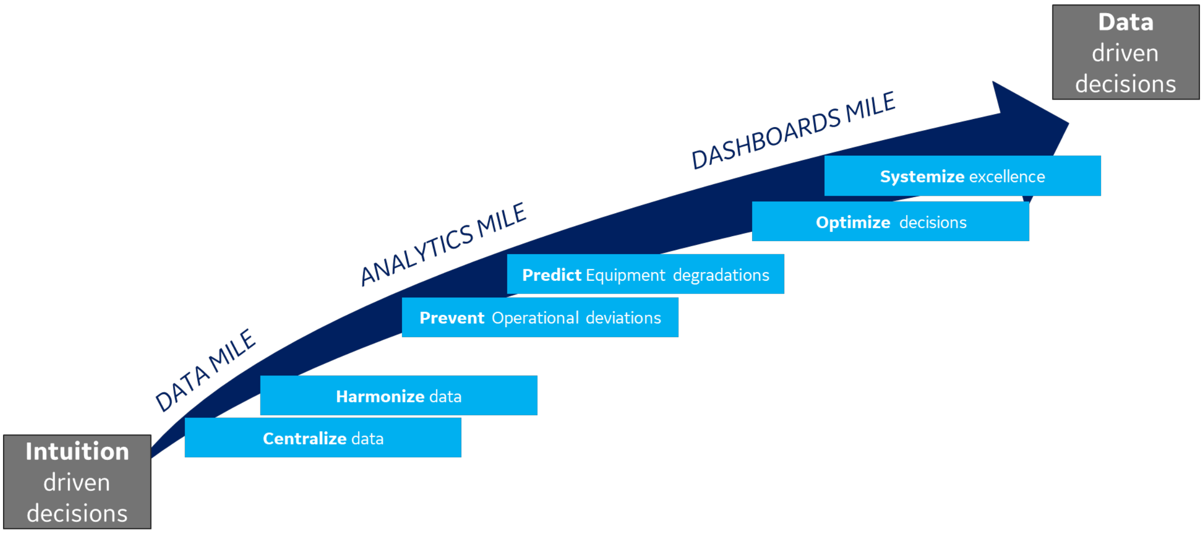

Figure 2: Data-driven decision model.

- **Data mile** –. Data is gathered, structured, centrally stored and a mechanism provided to export data and analytics to internet based or onshore facilities for further analysis and storage.

  More data doesn't necessarily translate into more value - the key to unlocking real value from data is to filter out 99% of the "noise" and focus on 1% which can unlock real value.

- **Analytics mile** – Apply sophisticated algorithms and analytics to establish operational and asset models and use these to define norms, detect deviations and predict degradations and failures.

- **Dashboards mile** – Asset usage and condition can provide the final stage when owners and operators use the full data to optimise their decision-making processes. Analytics drive maintenance schedules, selection of operating configurations, identification of problem areas on specific assets/platforms and lessons learned applied fleet wide.

The user interface is key dashboards should not only look good, but be intuitive.

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6.1 Architecture

As important as having all the right functional building blocks is to have the right architecture that brings everything together and allows for:

a) Simple and safe connectivity of sensors

b) Reliable transmission of data from offshore to cloud or onshore facility, with cybersecurity at the core.

c) Accessibility of data to the team who will be making data-driven decisions.

d) Scalability to enable the system to grow over time as more assets get integrated and monitored.

An example architecture is shown in Figure 3

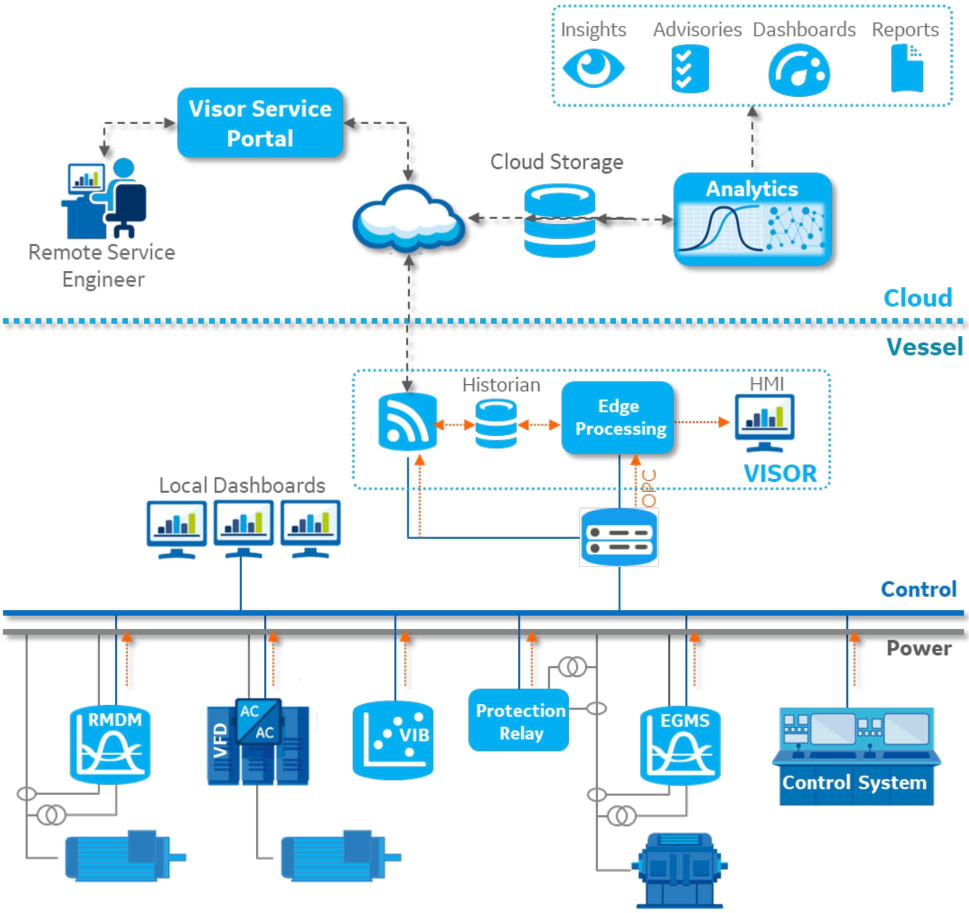

Figure 3 - Example Architecture

The architecture shows assets where data can be collected. This can be from existing or added sensors/instrumentation. (RMDM is the Rotating Machines Diagnostic Module used for capturing high frequency current, voltage and vibration data as well as lower frequency KPI data. EGMS is the Enhance Generator Monitoring System used similarly for monitoring health and performance of electrical generators)

The data is stored in a historian, processed and stored in a database, all carried out locally. This minimises the amount of data to be transferred from the ship to cloud or onshore facility.

Data can then be securely transferred where advanced analytics and machine learning are conducted. The off-site location also allows comparison between multiple sites or platforms to provider greater insights into performance.

Figure 4 represents an ESA solution deployed on a vessel with six identical alternators operating under similar conditions. The example shows the fault index (output from algorithm), with one machine clearly trending higher over the space of a few months. This data indicates a potential issue that requires attention weeks or even months in advance, providing notice to carry out corrective maintenance in a controlled manner, plan personnel readiness, ordering parts, etc, and schedule maintenance to avoid any disruption to operation.

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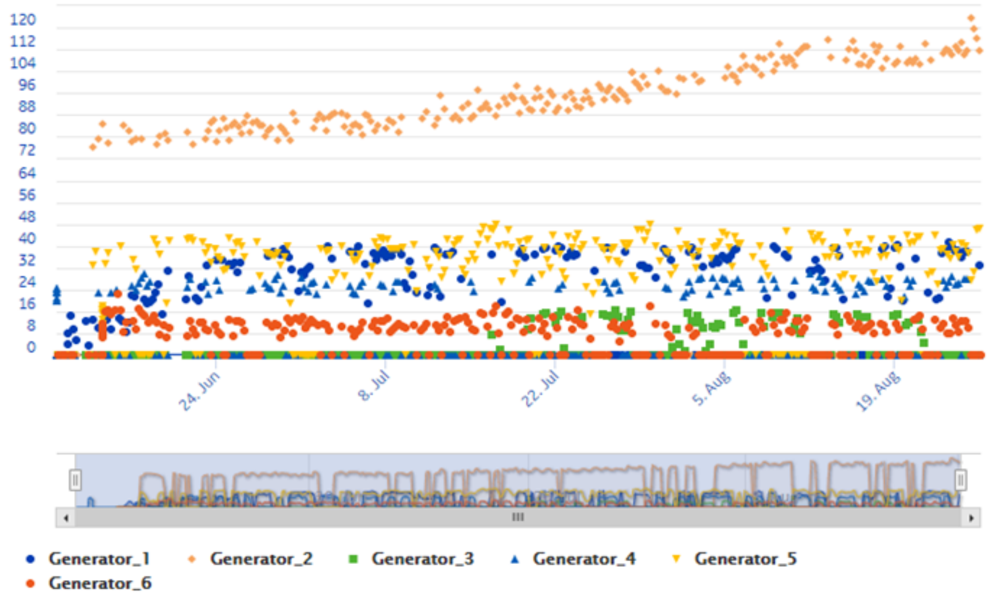

Figure 4 - Fault Index for Synchronous Generators

6.2 Vessel Optimisation

Dashboards shown in Figure 5 provide real-time insights into how much fuel a vessel is consuming and how an operator can re-configure the system to operate more efficiently – and with lower emissions. Reports can align with IMO fuel consumption reporting requirements.

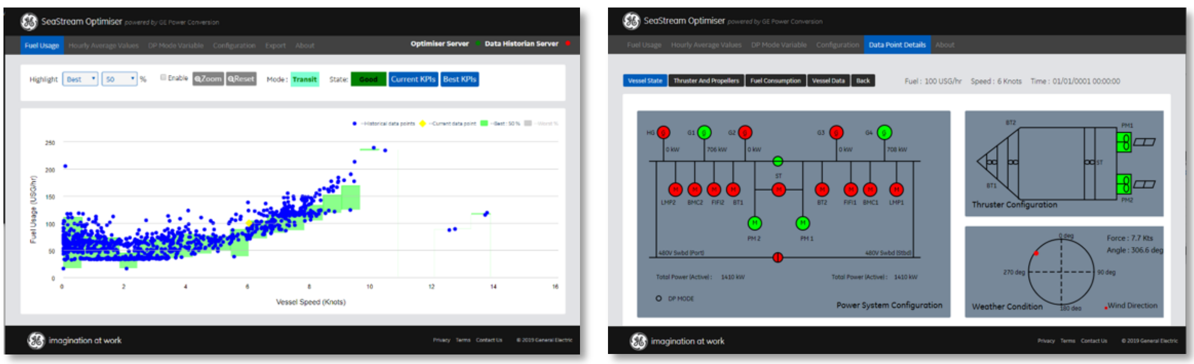

Figure 5 – Vessel Optimisation Sample Dashboards

Figure 6 shows a real example of vessel optimisation deployed on a vessel and data collected over a six-month period. During this period, the vessel was operated with either two, three of four generators online while transiting at a speed of 8 knots. It can be seen that fuel consumption can be reduced by ~20 USG/hr with three generators online, and a further ~20USG/hr with two online.

Thus, it is possible to save ~25% without sacrificing transit speed or integrity of the system (and having sufficient spinning electrical power reserve). This scenario is frequently observed as vessels are not always operated as designed, and operators are not always aware of the impact of their actions.

Operating with a reduced number of generators online reduces fuel consumption and emissions, improves overall efficiency and reduces wear on engines to prolong maintenance intervals by operating at a higher loading point. Showing the operator this information can help to change their behaviour.

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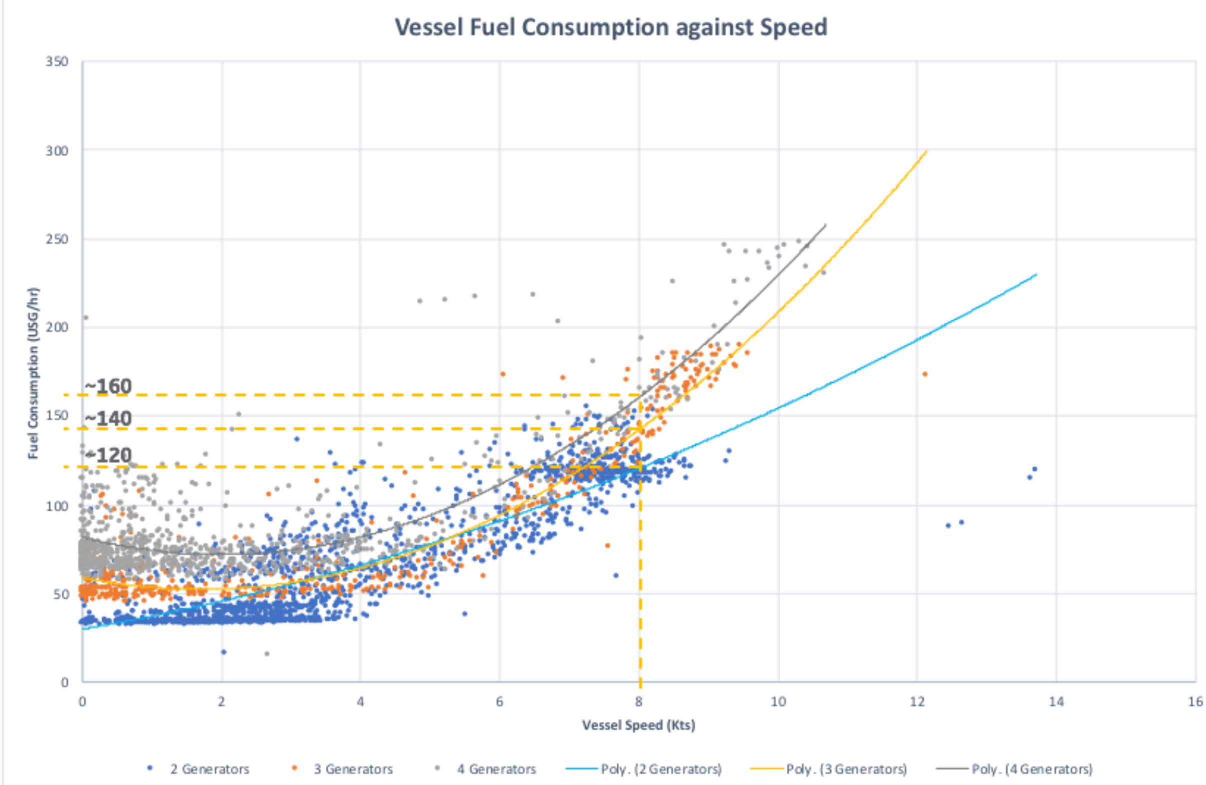

Figure 6 - Fuel Consumption Vs Transit Speed

6.3 Operations Optimisation

The example in Figure 7 shows how available data can be used to analyse operation efficiency on an offshore drilling vessel. Performance indicators are provided via dashboards both on board and on shore. This can provide analytics for performance and predictive insights along with providing predictability and repeatability in operational processes on a specific vessel or across the fleet, enabling shift to shift or vessel to vessel comparisons.

The dashboards provide performance insights of various activities, with a comparison against best achieved performance and technical best possible, ability to "drill-down" further into each activity and identify efficiency in performing each task, and ultimately selection of the best process efficiency and predictability in performance, all from historical data.

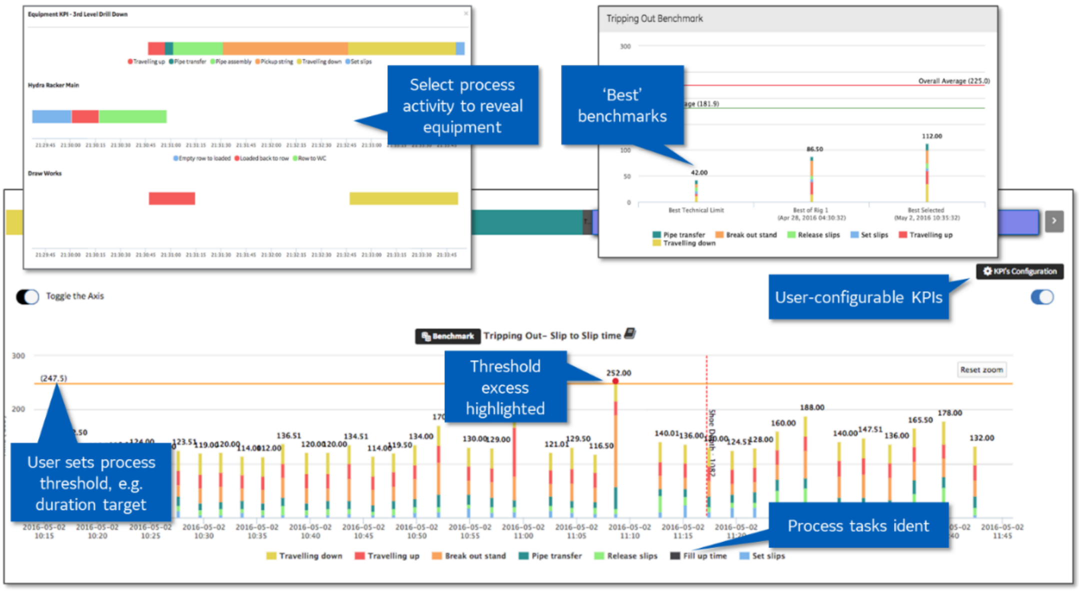

Figure 7 - Process Optimisation Dashboard

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Another example of optimisation can be cited in the use of dynamic positioning (DP) to maintain a predetermined heading and position by use of propulsion units to counteract the effects of displacing forces such as wind, current, and wave action.
Proven DP modes provide real economics by using predictive software to anticipate position variation and to limit thrust changes, if the vessel is expected to remain within the 'soft' operating window. If the vessel is predicted to move outside its 'hard' operating window the system develops optimum thrust to remain within that window. Advanced algorithms are used to optimize vessel heading to further reduce power consumption and limit thruster/machinery wear and tear.

Additionally, the DP system through increased data collection, processing and interconnectivity capabilities, provides predictive information to operators to enable effective decisions, ensure safety, avoidance of collisions, operation efficiency, a method of analysing the true capability of a vessel's DP and other key benefits.

7. Conclusion

Understanding machinery condition, economical systems configuration and reliability trends of assets are essential steps for operational excellence.

Asset Performance Management (APM) is a proven approach to reduce unplanned downtime, decrease maintenance costs, and reduce environment, health and safety (EH&S) risks. Implementing an effective APM strategy is more than installing a series of sensors or point solutions that monitor and track your systems and assets.

APM is an integrated, connected enterprise solution bringing together professionals from across the marine domain, combined with available data onboard vessels with smart analytics that enables asset-intensive organizations to drive safer, more reliable operations while facilitating optimal performance at a lower sustainable cost.

APM would empower companies to make informed decisions about their asset strategy by forecasting system performance and move towards a more productive, predictable, lower risk future.

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