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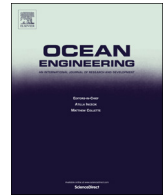
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## Integrated approach to vessel energy efficiency

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## ABSTRACT

Energy efficiency improvements in the shipping industry are being driven by economics, compliance and customer requirements. Whilst various technological and operation improvements are known and available, with many being demonstrated to be cost effective and with savings reported in the industry, their take up in the world fleet remains low. This low take-up can be considered due to many different barriers, as explored in various research studies. However the aim of this paper is first to understand how these barriers are created by considering how ship operations function day-to-day within the context of mainstream business practice. A holistic view of operations is required and is presented in this paper, including consideration of business focus areas in parallel with the functions of technical, operational and commercial stakeholders. With this laid-out, gaps within existing operations are discussed in relation to areas for practical improvements. From here, non-prescriptive mechanisms to enable a desired future are proposed; including the integration of mandates, processes and systems. Case studies are given throughout the paper using hull and propeller maintenance as a recurring example of a typical decision making processes and best practices.

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## 1. Introduction

Energy efficiency, fuel consumption optimization and many other terms have been used synonymously to address issues and initiatives alike. The drivers toward addressing these issues and initiatives can be summarized into three main driver groups: economics, compliance, and customer requirements. Elaborating on these groups, the need to achieve economic voyages is driven by bottom line profit margins. Given the volatility of daily charter rates, shipping demand and bunker prices (UNCTAD, 2014), the objective is to minimize operational costs and to maximize revenue. How this is achieved depends on company organizational structure, ship type and services operated (Stopford, 2008; Poulsen and Johnson, 2015).

*Abbreviations:* AIS, Automatic Identification System; BAU, Business As Usual; CAPEX, Capital Expenditure; CSR, Corporate Social Responsibility; EEDI, Energy Efficiency Design Index; IMO, International Maritime Organization; ISM, International Safety Management Code; ISO, International Organization for Standardization; KPI, Key Performance Indicator; LTIF, Lost Time Injury Frequency; MRV, Monitoring, Reporting and Verification; OPEX, Operational Expenditure; PBCF, Propeller Boss Cap Fin; RCM, Reliability Centered Maintenance; ROB, Remaining On Board; RPM, Revolutions per Minute; SEEMP, Shipboard Energy Efficiency Management Plan; UNFCCC, United Nations Framework Convention on Climate Change; VDR, Voyage Data Recorder

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The second driver group towards energy efficiency is compliance with regulatory requirements and company adopted standards. On 1st January 2013 the amendments made to the International Convention for the Prevention of Pollution from Ships (MARPOL) 1973/78, Annex VI, entered into force, forming the first regulations related to ship energy efficiency (IMO, 2012a). The regulations require all new build ships to comply with the Energy Efficiency Design Index (EEDI) which targets ship design (IMO, 2014), and all new and existing ships to have a ship specific Ship Energy Efficiency Management Plan (SEEMP), targeting ship operational energy efficiency (IMO, 2012b). Development and enforcement of these regulations by the IMO was in response to the requirement to start taking actions under the Kyoto Protocol (United Nations, 1998): an extension of the United Nations Framework Convention on Climate Change (UNFCCC) treaty (United Nations, 1992), addressing the need to mitigate detrimental climate change via the reduction of anthropogenic carbon dioxide (CO<sub>2</sub>) emissions (IPCC, 2014). On average, between 2007 and 2012 it was estimated that the shipping industry emit 3.1% of global CO<sub>2</sub> emission, 2.6% from international shipping alone. If no actions are taken these emissions are expected to increase from the 2012 levels by 50–250% by 2050 (Smith et al., 2014). Therefore significant changes are needed to meet existing (focused within a 2 °C climate change scenario) and future global emission reduction targets (Jordan et al., 2013). It has been identified that enforcement of the EEDI and SEEMP alone is likely to increase awareness and promote energy efficient ship design and operation, resulting in

savings; but not to the magnitude required (Bazari and Longva, 2011). Acknowledging one of the primary weaknesses of the current energy efficiency regulations, the EU adopted a proposal for Monitoring Reporting and Verification (MRV) in April 2015, which will enter into action on the 1st January 2018 (EU, 2014). It is estimated that MRV could contribute a 2% reduction to BAU shipping emissions by 2030 by taking a first step towards reducing market barriers; particularly those related to a lack of reliable and robust information on ship performance (i.e. fuel consumption, and hence predicted emissions) (EU, 2014). However, again there are concerns over the effectiveness of MRV in providing greater transparency. This is because the energy consumption monitoring practices are left to the industry to decide, which will not necessarily address the following four barrier challenges: data collection, misreporting, data analysis and feedback problems (Poulsen and Johnson, 2015). Further, to regulations, International Standards adopted by companies also act as drivers toward implementing ship operational energy efficiency; such as ISO50001 (BS EN ISO, 2011). An advantage of ISO50001 over the SEEMP is that it requires a verification method to be defined for each action (i.e. best practices) (Johnson et al., 2013). Further advantages of the ISO50001, and the codes such as the ISM code, over the SEEMP include: the requirement for mechanisms for reviewing energy demand, setting goals, monitoring performance; encapsulating company management rather than ship specific (Johnson et al., 2013). These are issues that still need addressing in the context of practical ship operations.

The third driver group toward the implementation of energy efficiency is customer requirements. Major organizations, i.e. those mostly listed in stock exchanges, promote the requirement for vessels chartered by them to carry their cargo to follow sustainability initiatives and practices as part of their commitment to Corporate Social Responsibility (CSR). With rising concerns over climate change mitigation, as previously discussed, energy efficiency and low carbon supply chains have become increasingly more important to customers and within CSR (M&S, 2015). There are several industry and working group initiatives and indices to acknowledge energy efficient ships and efforts. Svensson and Andersson (2011) discusses many of these in relation to their intended use, users (e.g. customers), basis and scope.

In light of the described drivers, initiative to increase ship energy efficiency has been extensively explored and researched and discussed in breadth and depth across the maritime industry (LCS (2014), Stulgis et al. (2014), ABS (2013) and Knott and Buckingham (2011) are only a few examples). Many of the initiatives are described in the guidelines for the development of the SEEMP (IMO, 2012b). Focusing on industry reported savings, some of the most commonly implemented initiatives include popular retrofits; such as Propeller Boss Cap Fins (PBCF), Mewis Duct, Stator fins, bulbous bow modifications, propeller change, and de-rating of engines. Armstrong (2013) reported up to a 4% gain in propeller efficiency with the installation of a Propeller Boss Cap Fin (PBCF) and De Kat et al. (2010) reported 1–3 g/kW h were saved after installing injection timing autotuning. Popular operational practices that have been implemented include slow steaming, Just-In-Time (JIT) arrival, weather routing, cargo heating management, and trim optimization. Example savings reported include a validated 1% from trim optimization, and fuel saving of 2.5 MT/day from cargo heating optimization (Armstrong, 2013). Popular maintenance practices include monitoring and timely maintenance of the main engine and onboard equipment, along with the selection of a best-suited hull coating system and hull surface preparation. For example, De Kat et al. (2010) identified a 70–80 kW saving by performing maintenance and optimization of the ventilation system and Armstrong (2013) reported a 2.5 MT/day fleet average fuel saving from a full blast of a hull after drydocking

in the 10th year of operation and using a Self-Polishing Copolymer (SPC) coating.

The above demonstrates that savings are achievable in the industry. Marginal Abatement Cost Curve also demonstrates that many measures are considered cost effective (Faber et al., 2011; DNV, 2010; IMO, 2009). However Rehmatulla (2012) describes a survey of primarily ship owners, charters, operators and management companies, that was carried out to assess the barriers to uptake of energy efficiency operational initiatives. The survey results demonstrated that even for the measures considered to have the highest potential for improving energy efficiency; only around 65–85% of the survey respondents had implemented them. 90–100% would be expected for the cost effective measures with easy implementation and short payback periods (Rehmatulla, 2012). An average implementation rate around 50% was observed across all the operational measures included in the survey.

With a low take up of energy efficiency measures in the industry studies have been carried to investigate different types of barriers. From the survey results Rehmatulla (2012) identified the most significant barriers to be the following: lack of reliable information on cost and savings; difficulty in implementing under some types of charter; lack of direct control over operations; materiality of savings. The survey results also revealed that smaller companies cited barriers more frequently than larger companies. Poulsen (2011) discusses and highlights the following as barriers: agency problems (split incentives); inadequate information and transparency for energy efficiency and incentive structures; information uncertainty; high discount rates being applied resulting in decisions made for short-term benefits. Poulsen (2011) also concludes that social science needs to be considered in addressing barrier to energy efficiency improvements, along with attitudes and incentive structures. Considering the perspective of 317 seafarers, survey results revealed the following as barriers to effective change: availability of education; communication between ship and shore, and internal and external stakeholders; transparency of limitations, capabilities, responsibilities and achievements towards energy efficiency improvements (Banks et al., 2014). Furthermore Poulsen and Johnson (2015) discuss the results from 55 interviews with technical and commercial personnel; highlighting data collection, misreporting, analysis problems and feedback as problems for energy consumption monitoring, which is a key barrier toward effective energy management.

In conclusion of the above, it can be considered that despite a body of knowledge, the adoption of best practices, lessons learnt, and new technologies continues to remain a challenge as part of mainstream business practices. Whilst different types of barriers to energy efficiency improvements have been explored it is first necessary to understand how they are created, as discussed in (Poulsen and Johnson, 2015). The aim of this paper is therefore to explore exactly this by taking a closer look at how ship operations function day-to-day within the context of mainstream business practice. This is done by first explicitly laying out the focus areas, stakeholders and functions associated with ship operations in an understandable matrix that can be related to most organizational structures (Section 2). With this laid-out, the type of gaps within existing operations are discussed (Section 3) in relation to practical ship operations. Hull and propeller maintenance is used as a recurring example throughout the paper, although similar principles could be applied to most decision making processes and best practices. A desired future is then proposed in Sections 4 and 5, not stating prescribed outcomes, but suggesting mechanisms to enable recognition of practical improvement areas to allow for improved integration and transparency in ship operations, and hence address several of the barriers to practical implementation.

## 2. Defining and understanding current practices for vessel operations

In this section the major focus areas, stakeholders and functions of ship operations are defined to ensure understanding of current operational practices in shipping.

### 2.1. Major focus areas

To summarize the major focus areas of vessel operations, they can distinctly be grouped into four areas namely; profitability, risk management, asset management and sustainability.

Profitability is a major area of focus leading to activities warranting increase in the number of days a vessel is available for service, minimizing the number of days of off-hire from charter for reasons like maintenance, reducing the operational expenditure, maximizing revenue with better charter rates and enhancing commercial operations. This is a key to the success of the organization and its vessels' operations, which in turn can address any requirement for further optimization as appropriate.

Risk management actions relate to the monitoring, follow-up and close-out (i.e. implementation) of mitigation measures that are related to health, safety, quality and environment. This is expected to be a very transparent area often emphasized during audits and certifications, and more importantly demonstrates the organization's efforts and commitment to caring for its staff; thereby remaining a significant area of focus.

Asset management is an area of focus where efforts are coordinated to retain the tangible asset value of the vessel, prolong the useful life of the asset and improving its reliability. Drydocking life cycle management, equipment life cycle management including maintenance and capital projects are undertaken to preserve the value of the asset.

Sustainability is a relatively new terminology and area of focus used by the increasingly "world-community" conscious maritime industry. Often defined by three P's namely People, Planet and Profit, these are fundamental building blocks to both the organization and the broader world community. A balanced approach to ship management is achieved by coordinating efforts through Corporate Social Responsibility (CSR) activities which include focus on emissions, training, awareness and well-being of its staff and the community around and of course the success of business itself in terms of its bottom-line profit.

### 2.2. Major stakeholders

Today the major stakeholders of vessel operations could be classified under three categories namely technical, commercial and operational. Stakeholders under the "technical" category include those responsible for strategic functions and services that support vessel operations strategically as an asset owner. Staff responsible for evaluating and approving capital projects, new building projects, standards and policies, third-party service providers, are some of the major stakeholders in this category. In the "commercial" category the stakeholders are responsible for revenue generation and commercial operations; including staff in-charge for voyage management, vessel trading, freight trading, chartering, insurance, demurrage can be classified in this category. The "operational stakeholders" are the ones responsible for day-to-day operations of the vessel in general, including the technical superintendents, fleet managers, crewing staff and other supporting functions like procurement and training staff. They are expected to operate within agreed budgets and ensure the vessel remains operational for commercial use.

A model to clearly distinguish each of the stakeholders discussed above is shown in Fig. 1. Commercial stakeholders utilize the vessel's services to generate revenue which is shared with the shareholders and is also routed back as Operational Expenditure (OPEX) to the operational stakeholders. The revenue generated is also used to fund Capital Expenditure (CAPEX) projects and support the Cost of Ownership of the vessels which are classified as responsibilities of the technical stakeholders.

### 2.3. The functions of vessel operations

Functions relate to the roles and responsibilities of the stakeholders. A conceptual framework has been presented in Table 1 to demonstrate the functions undertaken by different stakeholders in relation to the key focus areas. Whilst the presented framework is important for understanding how ship operations and functions can be perceived, it is important to note that no one company will follow the exact organizational structure.

For example, Table 1 shows that many of the functions fall under the responsibility of operational stakeholders. Yet in practice it is predominantly the technical stakeholders that are engaged in the energy efficiency discussions: i.e. via the design and choice of retrofits, upgrades and developing maintenance

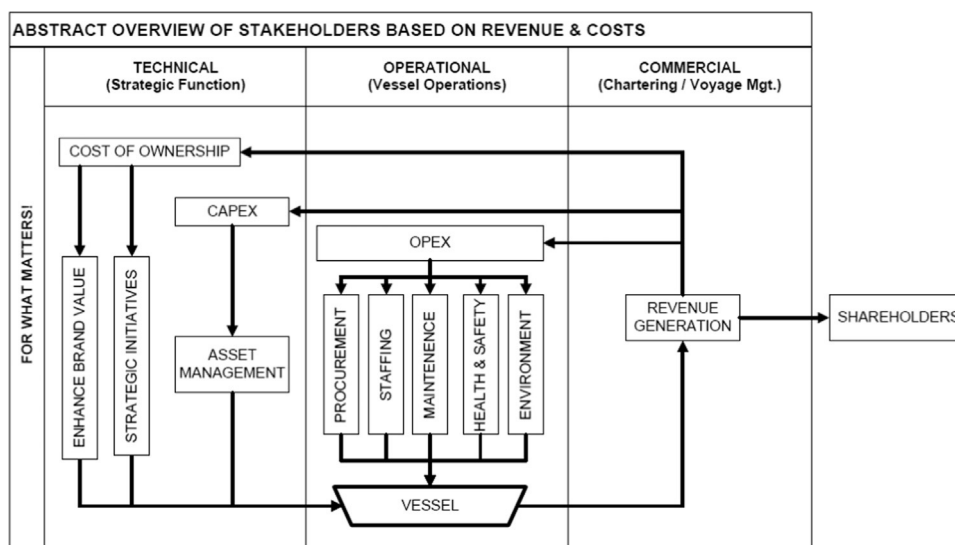


Fig. 1. Overview of stakeholders based on revenue and costs.

strategies where decisions are made based on reported data and their analysis, reference data like model test, sea trial, shop trial and research. While operational stakeholders have little experience in data analysis and developing trends, technical stakeholders have little involvement in holistic ship operations.

While effective communications between stakeholders could leverage the strengths of each other, current practices limit their interactions. Discussions are usually at the level of unit heads or department heads where strategic issues of priority are discussed. Tactical issues to be dealt with on a day to day basis by the middle management level staff tend to operate independent of each other.

In conclusion, it is emphasized that an improved integrated approach to performing vessel functions needs to be introduced to vessel operations where all three stakeholder groups should be engaged in discussions to determine practical, holistic and most effective solutions.

### 2.3.1. Typical ship functions applied to vessel dry docking and energy efficiency effectiveness

Based on the systematic distribution of functions among stakeholders, an illusion could be created that all aspects of vessel operations related to efficiency are addressed effectively and there could be very little scope for further improvement. However, to demonstrate the gaps in the dispersion of responsibilities in an

**Table 1**  
Lay out of functions for vessel operations.

	TECHNICAL	OPERATIONAL	COMMERCIAL
<b>Profitability</b>	Minimise CAPEX	Minimise OPEX	Freight Trading
			Chartering
			Voyage Management
		Commercial Performance Monitoring	
<b>Sustainability</b>	Retrofit	Crewing / Training / SEEMP	
	Technical Performance Monitoring		
	Optimization Initiatives		
		Health & Safety	
<b>Asset Management</b>	Capital Upgrades	Dry docking	
	Regulatory Requirements		
		Maintenance	
	Hull & Propeller Cleaning		
<b>Risk Management</b>	Incident Investigation & Follow-up		
		Awareness	
		Surveys	
		Quality / Reliability	

organization's structure, a snapshot of a vessel's hull prepared for coating during drydock is described in this sub-section.

While it is common industry knowledge and there has been a lot of research on the significance of hull roughness and its impact on performance over the docking life cycle of a vessel, spot blasting practices of the hull (Fig. 2) still continues to be a common practice (Anderson et al., 2003; Taylan, 2010).

Drydocking of a vessel, usually every five years, is an operational requirement and considered to be an operational expenditure (OPEX). This activity is dictated by a budget decided almost a year in advance and mutually agreed between stakeholders amidst various other constraints in an attempt to optimize OPEX. When the vessel is in drydock the time and resources are limited for reasons like days out of service, budget constraints, off-hire and availability of dock: this takes its toll on the effectiveness of this major maintenance activity.

The operational stakeholders' responsibility is to drydock the vessel and complete the tasks (e.g. maintenance and surveys) within the specified time frame and budget. Therefore, the operational stakeholder's responsibility could be considered "complete" when the vessel is picture perfect cosmetically and all survey requirements are completed at the end of the drydock. However, in this instance, the effect of increased hull roughness due to spot blasting and not full blasting, which heavily influences vessel performance, is subtly passed on to the commercial stakeholders. While the impact is not immediately obvious, over a short period of time, the added resistance increases steadily affecting ship's speed and increased fuel consumption. On some occasions, the quality of the chosen hull coating also plays a major role in the performance of the vessel over the docking life cycle.

If the commercial stakeholders were part of the drydocking planning process, an assessment of vessel's performance expectations over the docking life cycle, could be incorporated impacting docking requirements. Incremental budget to accommodate the performance expectations (e.g. full bare metal blasting of the hull up to SA2.5 standards, additional days required in drydock, better quality or additional thickness of hull coating) could all be proposed and approved.

To summarize, performing minimal maintenance at drydock to achieve savings of few thousands of dollars over the drydocking process is the mandate of the operational stakeholder and the fuel penalty costs after the drydock due to poor hull condition that could run into millions of dollars are borne by the commercial



**Fig. 2.** Hull prepared for coating – who's accountable and who's the beneficiary?

stakeholder. Moreover, such situations prompt the need for early or premature docking of the vessel before completing the normal life cycle of five years between drydocks. Challenges addressing such issues continue to remain, as one stakeholder's responsibility and accountability is not aligned with the other stakeholder but is the beneficiary of the outcome; thereby lacking coherence and synergy.

### 3. Discussion of weaknesses in present state of ship operations

#### 3.1. Multiple goals and targets

To summarize the present state of vessel operations, though the focus areas and the stakeholder responsibilities are clear, the major reason for ineffectiveness in achieving energy efficiency in vessel operations could be the lack of a coherent approach. Each of the focus areas exists as an independent entity for the organization and there is very little coherence in their approach to efficiency, Fig. 3.

There are multiple goals and targets to be achieved by the different stakeholders within the focus areas which are mutually exclusive. This leads to many challenges in adopting agreeable energy efficiency benchmarking practices within the organization and also the broader maritime industry. Focus areas are usually addressed through initiatives and the success of individual initiatives adds up to the bottom line profit, contributing to the efficiency of the organization.

As an example, Lost Time Injury Frequency (LTIFs) continues to be an area of focus and organizations drive initiatives and programs through the “operational stakeholders” to develop a safety culture onboard vessels. On the other hand, recent developments in large container shipbuilding where the design is mainly influenced by the “technical stakeholders” warrants shipboard accommodation in the midship section of the vessel while the engine room continues to remain in the aft part of the vessel. When the vessel is unmanned, either the duty engineer will have to race over 100 m and then few staircases to attend to the alarm in the engine room in the middle of the night or else stay in the engine room overnight to attend alarms. Similarly, the cosmetic look of the vessels, which is a responsibility of the “operational stakeholders”, continues to be maintained at the expense of crew, carrying out risky maintenance work whilst hanging on ropes over the side of the ship's hull whilst afloat.

#### 3.2. Performance monitoring

Some of the commonly reported challenges with today's vessel performance monitoring fundamentally revolves around data quality, which depends on the diligence of the crew recording the data (Logan, 2011) and on the instrumentation, measuring equipment and practices followed onboard. Since it is challenging to arrive at valuable conclusion from analysis of the reported

vessel data, installation of expensive automated data collection systems and fuel flowmeters are recommended. A reliable torque sensor and a Doppler speed log are also identified as important sensors to install for improved performance monitoring accuracy (Hasselaar, 2010), yet they are not installed as a common practice and have their own uncertainties. The different performance monitoring methodologies and data collection practices adopted by different stakeholders and commercially available systems have led to inconsistent benchmarking practices and the origin of issues related to performance monitoring continues to remain a question.

Misunderstandings generated when vessel performance monitoring analysis results are not aligned with voyage performance analysis results, leads to lack of trust and issues of accountability. These impact follow-up and close out of anomalies, flagged by the vessel performance monitoring process.

Elaborating on the differences between “vessel performance monitoring” and “voyage performance monitoring” practices followed, could explain the root cause for the challenges mentioned above. While voyage performance monitoring is more “commercial” in nature, vessel performance monitoring based on benchmarking is more “technical” in nature.

Vessel performance monitoring is meant for providing a status update on vessel's performance specifically the hull and propeller condition so as to plan maintenance as appropriate, while voyage performance monitoring is required for minimizing voyage costs, maximizing voyage revenue and to identify opportunities to improve voyage efficiency.

Since both monitoring methodologies use the same parameters like speed, power and fuel consumption, and due to their varied approach, ambiguity prevails. Some of the reasons are listed in Table 2 to enable comparison.

The above differences contribute to most inconsistencies in performance monitoring practices. While there are various manual log book entries made onboard, a common practice is sharing of operational data recorded at noon with the shore based offices in electronic format, mainly meant for commercial use. Utilization of this data for vessel performance monitoring poses its own challenges as noon data is a grouping of cumulative and instantaneous data. As an example, parameters like distance traveled and fuel consumed are cumulative data measured over the past 24 h while engine power, weather conditions, currents etc. are instantaneous data. However accurate the analysis and benchmarking, more data will be required to observe meaningful trends. This leads to reactive maintenance of the propeller and hull after the deterioration is well established and confirmed rather than planning proactive maintenance based on forecast and projections.

### 4. The proposed desired future: an integrated approach

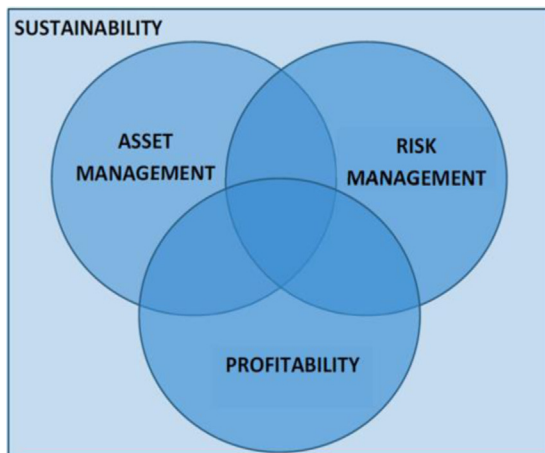
Looking further, with independent areas of focus, there are multiple goals to be achieved which lack congruence. The Key Performance Indicators of each of the stakeholders to assess their



Fig. 3. Present state of vessel operation, independent focus areas.

**Table 2**  
Reasons for misunderstandings in performance monitoring.

Vessel Performance Monitoring	Voyage Performance Monitoring
Technical stakeholder's interest	Commercial Stakeholder's interest
Benchmarked for defined displacements of laden and ballast conditions	Based on varying displacements, identified as ballast/laden passage, cited by vessel
Monitored for specific conditions referenced to sea trial	Average speeds and fuel consumptions as performed by the vessel
Excluding the effect of currents	Includes the effect of currents
Slip is differentiated between weather and performance	Slip is the only criteria to ensure data quality
A 10% slip is approximately 1–2 knot drop in performance depending on vessel type	A data filter of 10–15% slip is applied to ensure data quality
Referenced to benchmark conditions	Referenced to warranted figures provided to the charterer
Considers actual fuel consumptions excluding wastage	Fuel consumptions and wastages grouped together
Fuel consumption based on flowmeter readings	Fuel consumption based on ROB from tank soundings



**Fig. 4.** Desired approach for vessel operation, integrated focus areas.

own performance are opaque and mutually exclusive lacking transparency and inclusiveness. Success of initiatives undertaken is independent and do not have the desired multiplier effect from synergy by collaboration. While there is some amount of success from individual initiatives contributing to the bottom-line profits, the cumulative benefits from leveraging each other is lost. In summary, the benefits are short-term focused which could also be resulting in long-term losses often being overlooked.

While there is a lot of overlap between each of the focus areas discussed above, the responsibilities and accountabilities continue to be independent of each other.

To achieve an integrated approach, firstly the focus areas for ship operations need to be integrated which are mandates, processes and systems. These areas of integration are discussed in the following subsections.

#### 4.1. Integration of focus areas

Focus on sustainability for the sake of Corporate Social Responsibility remains an add-on effort and is vulnerable to market fluctuations. Hence, focus on “sustainability” should be the backdrop or platform for the other focus areas as well. Since sustainability focus addresses profitability of an organization as well, success of business remains always relevant. Fig. 4 demonstrates an integration of sustainability, asset management, risk management and profitability.

#### 4.2. Integration of mandates

When developing mandates, it should be endeavored to unify the objectives of stakeholders to leverage each other that would synergize the organization. Effective implementations of mandates are monitored through the use of Key Performance Indicators

(KPIs) to measure stakeholder performance or organizational effectiveness. Conflicting KPIs between stakeholders that would counteract should be avoided, as demonstrated in the following examples. An example KPI for operational stakeholder is number of “Off-hire days” per year, meaning the number of days a vessel was taken out of a charter for reasons like vessel maintenance, while KPI for the commercial stakeholder is number of “Idle days” per year, meaning the number of days the vessel was not trading or chartered out. In the event of a vessel requiring hull cleaning or propeller polishing, the operational stakeholder would not want to take the vessel “Off-hire” but wait for an “Idle day” while the “commercial stakeholder” would always try to avoid an “Idle day” and “Off-hire”. Another conflicting set of KPIs are “Fleet availability” for the operational stakeholder and “Fleet utilization” for the commercial stakeholder. Again, while the operational stakeholder would endeavor to maximize “Fleet availability” by avoiding pulling vessel out of service for maintenance, the commercial stakeholder would try to maximize “Fleet utilization” by chartering vessels as much as possible.

Another consideration associated with KPIs is that a common practice followed for monitoring organizational effectiveness is to use a more lagging indicator KPI(s). Lagging indicators measure the after effects; for example, monitoring LTIFs and incidents on an ongoing basis year after year. A good balance of leading indicators should be used to measure operational effectiveness which can help ensure performance improvement of vessels. For example, monitoring the number of propeller polishes or hull cleanings carried out (a leading KPI) is a proactive approach rather than just monitoring the number of performance claims made by the charterer, due to their poor performance of vessels and not adhering to the warranted speed and fuel consumption (a lagging KPI), which is a mere after effect.

The monitoring of onboard fuel consumptions is a key parameter, often used as or within KPIs, that should be considered for unification across stakeholders. At present the majority of the commercial charter party requirements limit fuel consumptions to main engine, auxiliary engine and auxiliary boiler for various speeds to be performed by the vessel and during port stays. But in reality, there are many other challenges onboard requiring staff to reconcile fuel ROBs onboard on a day-to-day basis, mostly based on fuel tank soundings. For example, there could be as much as 1–2% fuel waste generated from the fuel tank drains and purification process. Additionally, there are other consumers like incinerators and pilot fuel requirements onboard which require to be squeezed into the reported fuel consumptions for main engine, auxiliary engine and auxiliary boiler as required by the charter party. Small errors due to rounding of fuel tank measurements arising from bunkering short, trim correction, volume correction and temperature correction are also required to be reconciled as well for which there is little provision for transparent reporting for the commercial stakeholder or the charterer. While all the required

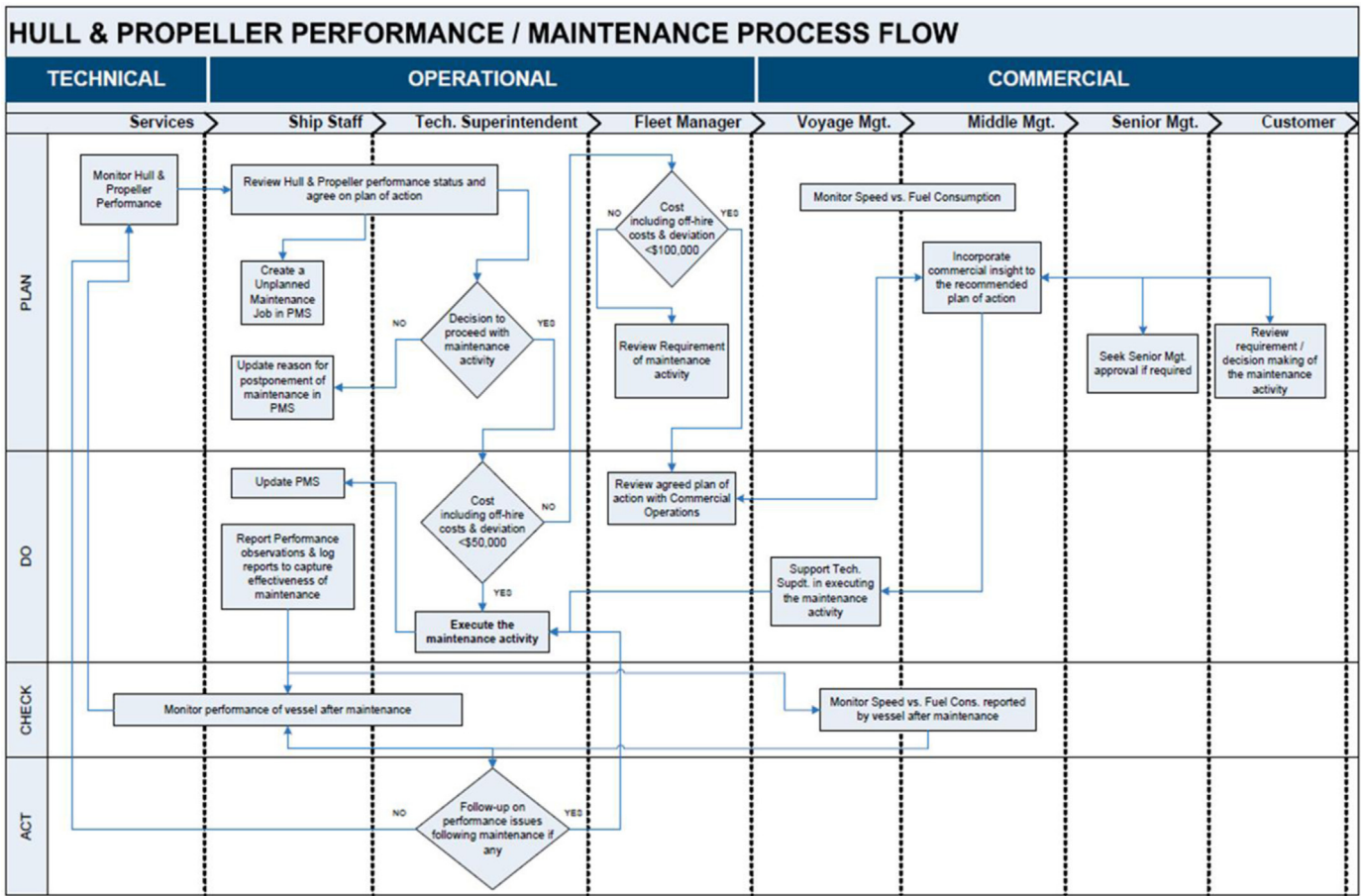


Fig. 5. Example hull and propeller performance/maintenance process flow.

information is perfectly reported in the engine room log books and oil record books, data is adjusted to the required format to meet the commercial reporting requirements. This is another reason for ambiguity in reported performance data.

#### 4.3. Integration of processes

A systemic or process based approach to implementing operational changes and energy efficiency optimization is required as it streamlines the flow of information and responsibilities for effective and informed decision making. Therefore, when reviewing decision making processes for purposes of integration, a holistic approach to the process design should be envisaged.

To explain this further hull and propeller cleaning is again used as an example. Hull and propeller cleaning is a maintenance activity that yields immediate benefits in terms of increased speed and reduced fuel consumption and emissions with an appreciable payback depending on the extent of fouling. However, the window of opportunity available to execute such maintenance is usually narrow as the vessels are normally engaged in some form of charter; thus optimizing the process and decision making is difficult. Fig. 5 presents a business process flow for hull and propeller cleaning in an organization demonstrating the convoluted decision making and execution process of the maintenance activity. The interactions between various stakeholders in a typical organization are shown in the flowchart. The interlinking processes within and between stakeholder groups when sketched on a sheet of paper could be quite complex.

Individuals part of the stakeholder groups endeavor contributing to accomplish their mandate, complicating the decision

making process. While organizations could have levels of approval based on title and designation, decision making on a timely basis could become a challenge. As in the case of the process map shown, escalation for approval at different levels with different stakeholders can be a time consuming process. Realization of such complications could simplify the approval process enabling speedy action.

Additionally, in bigger organizations, though the roles and responsibilities of individuals are clear, the business process flows are often not an area of focus as it could potentially minimize normal process loss. Business process flows once established offer scope for optimization and to perform gap analysis of accountabilities of the various stakeholders involved in the energy management process. Also, the interactions of stakeholders should be considered collectively, rather than optimizing them individually, enabling the gap analysis to develop the integrated approach.

An integrated and optimized approach in such cases require quick decision making by limiting the number of representatives involved in each stakeholder category. This requires delegation of responsibilities at an organizational level and diligence in implementation and execution.

While hull and propeller cleaning is not a major maintenance activity for the staff onboard as it is usually contracted out, interactions between stakeholders responsible for the execution of this activity at various levels can be complex. The resulting failure to execute the hull and propeller cleaning in time due to the complexity in business process flow leads to operational challenges like reduced speed, higher thermal load on the main engine, commercial challenges which include performance claims from charterer apart from higher emissions due to increased fuel



consumption until the next window of opportunity for maintenance presents itself. This is just one example and a similar process could be adopted to streamline other business processes as well.

#### 4.4. Integration of systems

There are numerous log books onboard a vessel (example of only a few including: the engine room log book, navigation log book, cargo log book, oil record book) and there are also numerous systems installed onboard to meet different requirements (including but not limited to: performance monitoring, structural integrity, weather routing, electronic data collection). Immense data is gathered manually and electronically but operational decision making for optimization continues to remain a challenge. Without integration of systems and data collected, they would continue to remain as systems and not a solution. It is expected that the staff onboard should decipher the information or data gathered by the different systems onboard, service providers and shore staff, and then implement optimized operations onboard the vessel. With minimal staff onboard it could be a far stretch to expect integration of information and analysis provided by different systems.

For instance, trim optimization is considered to offer potential fuel saving opportunities but most often left to the staff onboard for its implementation. While a lot of sophistication is involved in modeling and analysis in form of CFD calculations for the trim tool, the eventual trimming of the vessel continues to remain a manual process. Many factors influence a vessel's trim on an ongoing basis

including ballast exchange, fuel consumption of the vessel, weather and operating conditions. These require the vessel's trim to be adjusted regularly and a manual process is less desirable as some of the other factors come into play including the bending moments and shear forces of the vessel, moving of ballast water or cargo between tanks which complicate the process. There are other systems onboard the vessel, for example loading computer and stress monitoring system, which could incorporate the trim modeling input thereby ensuring optimal trimming of vessel is always in practice.

It is thus emphasized that there should be an integration of the systems used onboard ships, to allow for analysis and distribution of consistent and not conflicting performance feedback: minimizing the responsibility and burden of integration by staff. Fig. 6 demonstrates the onboard systems that should be integrated as an example to provide such a solution, encompassing the requirements of all stakeholder groups.

Benefits of such integration would include reduced administrative load by avoiding duplicate, triplicate manual data entry onboard vessels and most importantly improve transparency. While the primary paper log books onboard vessels are auditable, data reported electronically for performance monitoring are not auditable which could also be one of the root causes for the challenges with data integrity. Expensive instrumentation are installed onboard to automate the data capture process from the source to circumvent the challenges faced with data integrity. Transparency of data enables accurate performance monitoring analysis and also improves accountability of relevant stakeholders.

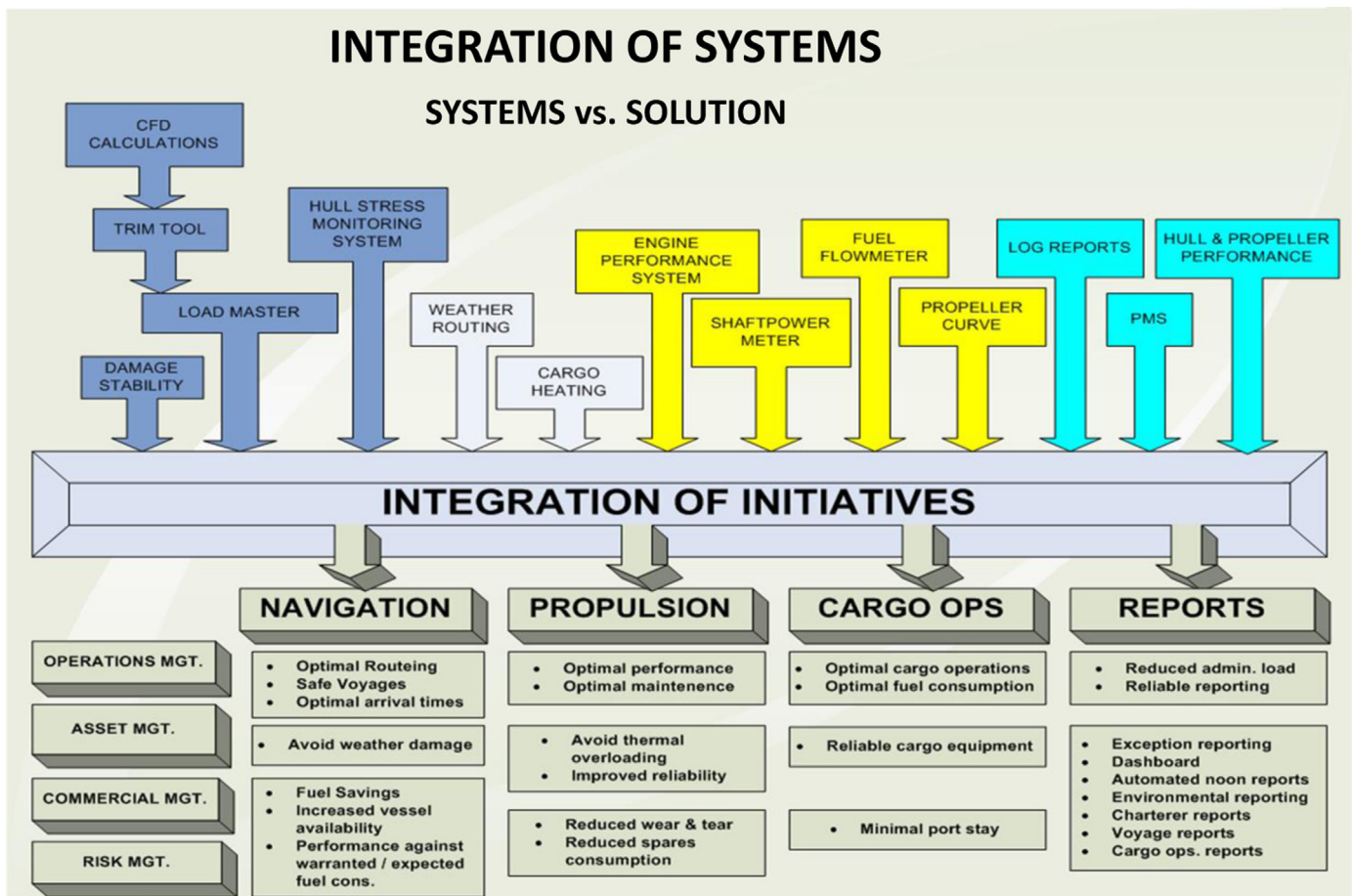


Fig. 6. Integration of systems.

## 5. Accepting reality

Enhancing operational optimization by integration of mandates, systems and processes enable the effectiveness of energy efficiency achieved by the vessel. However, in reality this needs to be supported by the development of consistent and understandable benchmarking practices, sharing and acknowledging other stakeholder contributions and quantification of efforts and results.

Benchmarking practices are critical as a vessel along with its equipment, starts to deteriorate soon after it is delivered from the new build shipyard. Improving or enhancing the operational or performance efficiency of a vessel is about optimizing the rate of deterioration. It is therefore necessary to develop standard models for acceptable benchmarking practices for initial performance, actual performance and acceptable rate of deterioration over the asset's life. This is necessary so as to quantify efforts and to demonstrate results.

Since all stakeholders belong to varying educational backgrounds and experience, there are only certain terminologies that are commonly understood by all of them. Communicating inefficiencies, fuel penalty and cost avoidance by quantification in a commonly understood terminology e.g. in terms of cost or lost revenue effectively communicates gaps and consequences by simplifying understandability.

While effective ship management, operations and revenue regeneration are equally important, recognizing and acknowledging each other's contribution is critical. Organizationally, the few measures that could be taken to this effect include; the promotion of cross-functional training and education among stakeholders, pay parity and moving away from the regular Annual Reports (which are mere financial reports) to Integrated Reporting which should include financial results, sustainability report and Corporate Social Responsibility (CSR) report.

Integrated reporting recognizes the contributions and achievements of all stakeholders thereby improving transparency and perception of the organization within and outside. Initiatives undertaken to improve efficiency and reduce emissions, training and awareness campaigns for staff combined with trends of Key Performance Indicators could drive organizations to fetch better charter rates and influence shareholders.

## 6. Conclusions

In review of this paper, it has been emphasized that to achieve practical energy efficiency improvements in the industry, technical solutions alone are insufficient. A systemic solution that undertakes an integrated and coherent approach to ship operations is required. Stakeholder engagement strategies, defined responsibilities and accountabilities, shared goals and objectives among stakeholders are required to enable realization of improvements and effecting energy efficiency. This could be achieved by ensuring that there are a defined set of KPIs for each stakeholder to address their own performance and an equal number of KPIs that are shared across all stakeholders to meet common objectives. Additionally a balance of leading and lagging KPIs are required to ensure corrective actions are taken in time. Moreover, interactions at all levels of the organization and stakeholders are required to develop the synergy to explore and maximize optimization potential. Sustainability should be the backdrop or platform for asset management and risk management practices as it addresses the profitability of an organization as well as the business success; including caring for its employees, customers and the environment. Furthermore, to achieve best energy efficiency improvements, focus areas for integration should include mandates of

stakeholders, systemic perspective of interactions in business processes and transforming systems to solutions. A communication protocol for quantifying aspects of performance is required that is simple, transparent, consistent and representative of commercial, operational and technical stakeholders.

It is recommended that further research is carried out to identify and address the barriers to energy efficiency improvement related to the functions of day-to-day vessel operations and processes within the context of main stream business practices. For example, it is suggested that operations based on "System's Thinking" and review of business processes followed within other industries, such as the airline industry, should be examined for transferable mechanisms to enable and encourage efficient business practices. Additionally, development of models for acceptable rates of deterioration of performance over the asset life is an important area for research to quantify benefits and other benchmarking practices.

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