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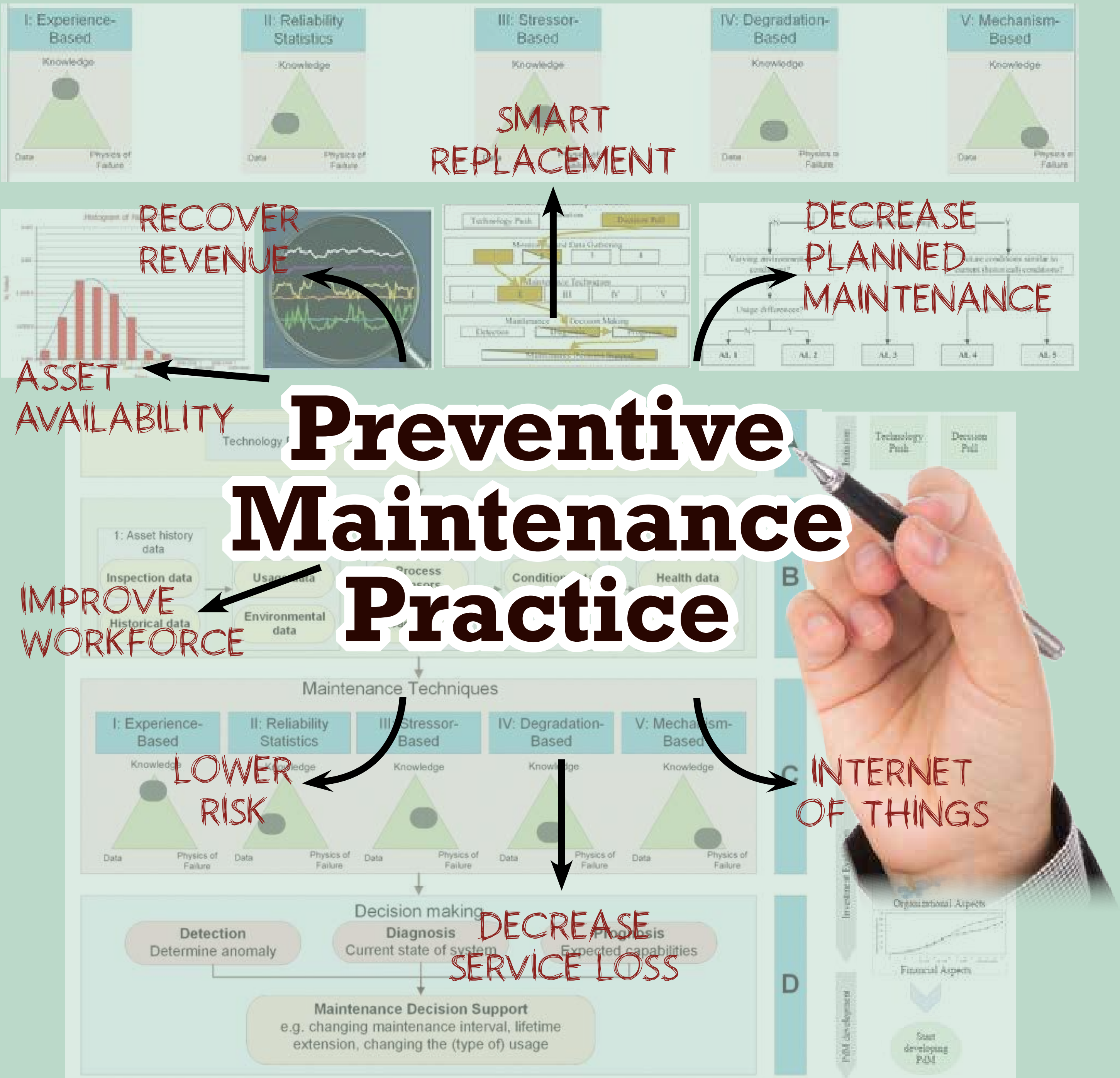
Preventive Maintenance Practice



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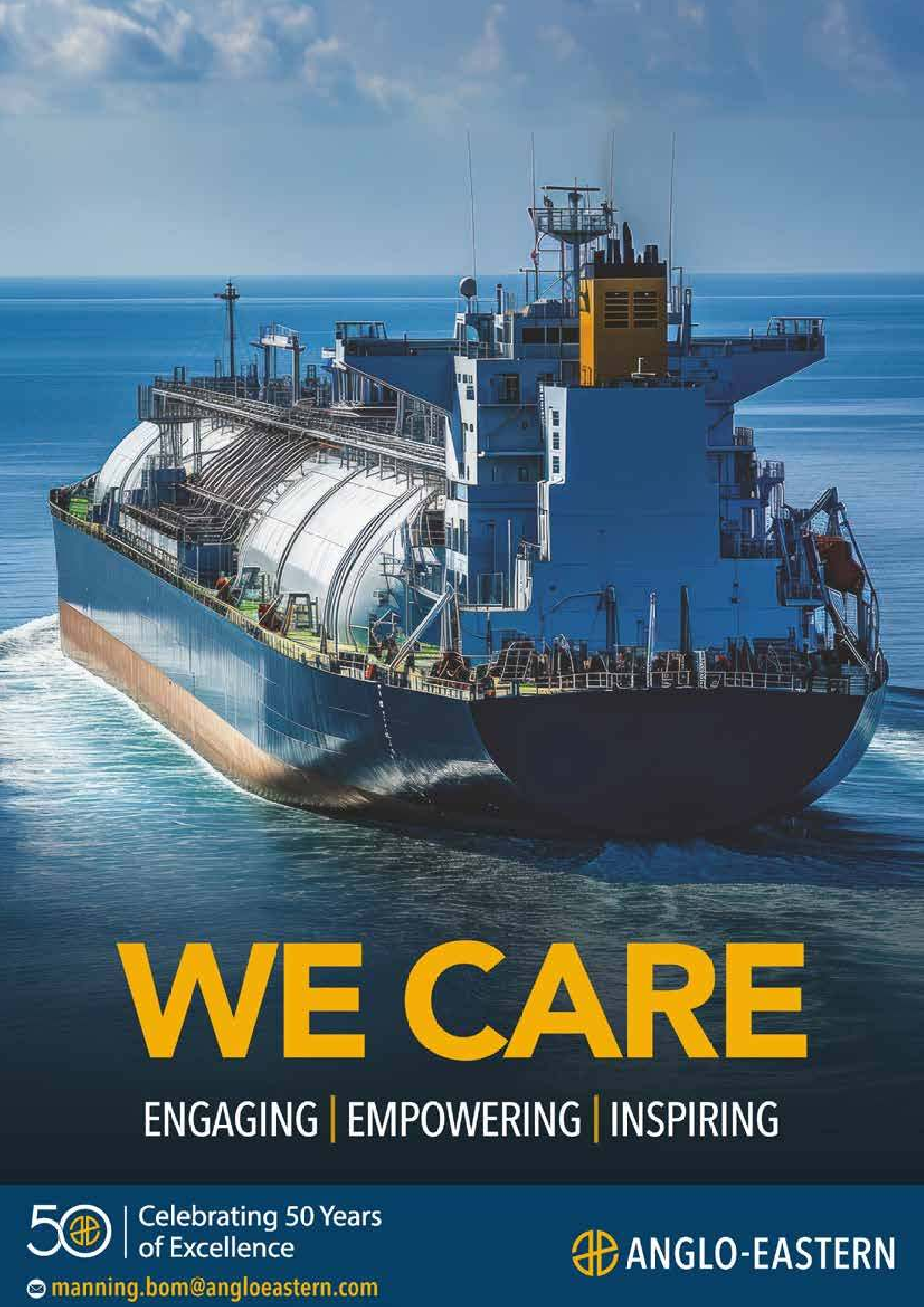
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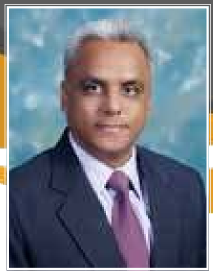

Not everything that can be counted counts.
Not everything that counts can be counted.

- (generally attributed to) Albert Einstein

The announcement on the launch of Bharat Container Lines has brought Shipbuilding back in the talks and tongues of maritime stakeholders. Undeniably, construction-manufacture of two products have to be given a good fillip: container ships and containers. The much-laundered reasons and merits of boosting shipbuilding are gaining heft. Indian fleet counts to 1500+ ships (12-15 million GT) and the average age of vessels is over 15 years, with many being out of the teens in their twenties. It is no brainer to say that this tonnage needs replacement, leave alone the argument for addition of tonnage.

India has about 30-50+ shipyards. The capacity and equipment vary from adequate to abysmally low.

If the yards are brought up to standard and the replacement tonnage is constructed herein, it will be an adrenalin shot for the fledgling sector. And the orderbook of defence builds will keep the yards busy for the next decade at least. The ancillary industries will need space and scope to expand around the yards, resulting in an organic growth. Jobs will multiply (shipbuilding has a multiplier effect of 6-8). That will be Atmanirbhar Bharat on track towards 2047.

Container manufacturing is riddled with quality and financing woes. Raw materials supply and procurement of manufacturing equipment have not seen the expected enhancement, post-pandemic. The importance and urgency felt due to the shortages have lost steam. Yet container manufacture stays as a comparatively easy product in the MSME portfolio. This needs oxygen.

Both the ₹25000 Cr. Fund, ₹8000+ Cr. shipbuilding financial support are countable measures. Reduction of duties for shipbuilding components, operational comfort in logistics, GST relaxations/exemptions etc., can also count. Industry pundits reckon the input tax credit accruals available with yards can be of help. All this requires a comprehensive policy revamping with shipping as the omphalos. Else, we will be counting our tonnage which will not couunt.

In this issue

We start with a discussion on Preventive Maintenance. Prabu Duplex has been indoctrinating maritime practitioners towards scientific approaches to maintenance. In the current exposition, few preventive maintenance approaches are well discussed and then the finding the ambition level (the level of date required for maintenance decision) is clarified and finally how the approaches, ambition level and the data types alignments, are explained. Though it gets a bit tricky through the words and tables, the decision making enigma will interest the marine engineers.

Following this is a paper from WMTC on Sustainable Development for Maritime Industry. David Adkins presents the model from the perspective of climate change. Three pillars of People, Planet and Profit are taken to fit in a Thematic Analysis, which in turn is brought into a Template Analysis. The participants in the interviews for building up the themes are from the maritime sector. The description of the methodology is brief and then there are findings with a few short discussions. The Summary of the Data Analysis gives a better insight into the study exercise. This is an easily followable read.

We pick another paper from the WMTC on lines of sustainable solutions. But in this instance, it is a method for treating ballast water. Prince Jeba Kumar et al., present a sand bed filtration system (shore based) and mention that a pilot plant with a seabed bore at 1.5 m water depth yielded 99% plankton-free filtered seawater and further tests at laboratory level had been encouraging. Considering the shore area requirements with sandy beds and the volumes of ballast which would be needed, the concept and idea needs further investigation. This can connect well with all mariners.

The Technical Notes section carries advancements in marine engineering put together by a group of marine engineering students and presented at the WMTC 2024.

MER Archives April 1985 carries an interesting Transaction, 'Evaluation and Prevention of Electrostatic Hazards associated with Oil Tanker Operations'.

I take this issue for another appeal. We have been applying elbow grease to transform MER as a Professional Journal of repute that carries quality articles across the range of maritime allied topics. The rationale for **iMélange** and shifting of a few sections was aimed at this change to make MER sober and inclusive. Yet our heart lies in marine engineering and ship technologies. We need matter from marine engineers and their minds for ideas. I earnestly appeal to the readers to send in submissions. There is scope under 'Spanner in the Works', where we discuss shipboard problems and MER Archives, where many topics connect well with marine engineers from now and then.

Here is the April issue as the summer and the cricketing interests swell.

Dr Rajoo Balaji
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Framework for the Selection of Preventive Maintenance Approach

Prabu Duplex

Introduction

The objective of this work is to help maritime practitioners in selecting the optimal preventive maintenance approach for their situation, by proposing a framework that provides support in these decisions. This work addresses primarily the classification and analysis underlying the following: Analysis of the range of preventive maintenance approaches; classification of the various ambition levels in preventive maintenance and the available data types; and linking of approaches, ambition level and data types.

> *Maintenance techniques should support managers in maintenance decision making by providing information about the current, and preferably also the future (predicted), performance of assets*

Selecting the Proper Maintenance Policy

Maintenance techniques should support managers in maintenance decision making by providing information about the current, and preferably also the future (predicted), performance of assets. However, they experience difficulties in the selection of the suitable maintenance technique to apply. The main difficulties that hinder the selection and application of the suitable maintenance technique is discussed in this section.

Selection of Appropriate Preventive Maintenance Approach

A maintenance approach consists of selecting a proper maintenance policy, as well as the maintenance techniques (MT) for operationalizing this policy. Although many methods for maintenance policy selection are available (such as reliability centred maintenance (RCM)), methods to select the required MTs are few.

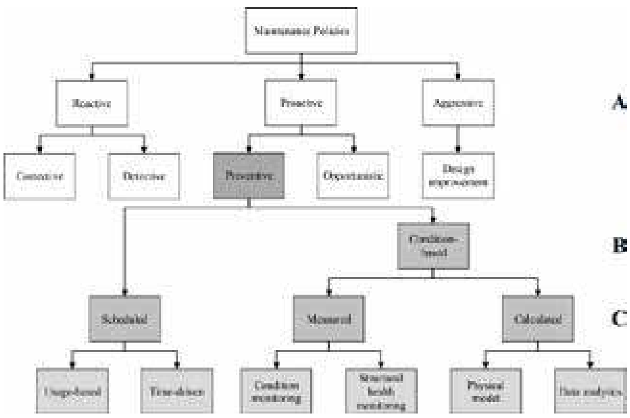

Figure 1. Overview of maintenance policies

As shown in **Figure 1**, on the highest level (A), a classification is made between reactive, proactive and aggressive policies. The preventive maintenance branch is then subdivided into various policies on the levels B and C, where they start to interact with the maintenance techniques (e.g. condition monitoring, prognostic methods).

The commonly used policy selection methods, like RCM, support the selection on level A and in most cases also on level B. For the selection on level B, various methods are available in the literature that incorporate specific factors, such as for example practical factors to consider in comparing condition-based with time-based maintenance as shown in de Jonge, Teunter, and Tinga (2017). Although these methods help to incorporate various factors in the selection of maintenance policies, the detailed selection on level C is not supported by these methods, as that is typically the level where a MT must be selected.

It is important that the selected combination of policy and MT suits, amongst others, the company's expertise, current situation, maintenance organization, assets and the use of their assets. Especially when practitioners are dealing with approaches that are new to them, there are many possible pathways towards better-informed maintenance decision making, but they find it difficult to determine the relevant methods and parameters to select. Difficulties arise to identify and distinguish between the suitable paths. To avoid a long and costly trial-and-error process, either external consultants are hired, or the techniques are not developed at all.

A set of initial solutions to select the appropriate maintenance approach is discussed in the following paragraphs. The structuring and classification of maintenance policies, methods and techniques, as well as the definition of ambition levels and data types is also discussed subsequently. One solution is to differentiate between various available preventive maintenance approaches. The framework now comprises of five types of preventive maintenance approaches:

I. **Experience-based predictions of failure times** are based on knowledge and previous experience outside (e.g. OEM) or within the company. Sometimes they are supported by little or scattered data. Predictions are based on expert judgement (e.g. facilitated by FMECA techniques). These methods estimate the life of an average component operating under historically average conditions.

II. **Reliability Statistics prediction techniques** are based on historical (failure) records of comparable equipment without considering component specific (usage) differences. This approach accurately describes population-wide failure probabilities. These methods also estimate the life of an average component operating under historically average conditions and are based on e.g. Weibull or normal distributions.

III. **Stressor-based predictions** are based on historical records supplemented with stressor data, e.g. temperature, humidity or speed, to include environmental and operational variances and give results in terms of expected lifetime of an average system in a specific environment. Predictions are based on the extrapolation of a general path derived from a physical model, build-in-test results, or operating history.

IV. **Degradation-based predictions** are based on the extrapolation of a general path of a prognostic parameter, a degradation measure, to a failure threshold. By measuring symptoms of incipient failure, e.g. rises in temperature or vibration, the system can be diagnosed. The prognostic parameter is also inferred from sensor readings, i.e. is always based on a measurement. The prediction starts from the current state of degradation and results in an expected remaining lifetime of a specific system in a specific environment.

V. **Model-based predictions** give the expected remaining lifetime of a specific system under specified conditions. Two types of model-based approaches can be followed:

A. **Physical model-based:** The prognostic parameter is calculated using a physical model of the degradation mechanism based on direct sensing of the loads or usage that govern the critical failure mechanisms of individual components.

Stressor-based predictions are based on historical records supplemented with stressor data, e.g. temperature, humidity or speed, to include environmental and operational variances and give results in terms of expected lifetime of an average system in a specific environment

B. **Data model-based:** The prognostic parameter is calculated or inferred using data analytics that uses sensed variations of loads, usage data, process data, or condition/health monitoring data as input. The algorithms aim to derive patterns or relations in the data or try to detect anomalies by comparing with historical data. The five approaches all combine specific maintenance policies with certain methods and techniques. To clarify the link between policies

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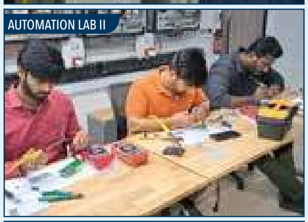

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and the proposed approaches, **Figure. 2** schematically shows their relation.

An important aspect differentiating the various approaches is how specific the lifetime of a system can be predicted. The lower maturity methods of experience-based (I) and reliability statistics (II) cannot predict the lifetime of an individual system or for a specific operating condition, they only provide fleetwide and long-time averages, e.g. an MTBF value. This branch is therefore denoted 'fleetwide' in **Figure. 2**. The more advanced approaches III, IV and V are based on condition-based policies, which do differentiate between individual systems or operating contexts. However, a model-based approach (V) can also predict the lifetime for not previously encountered situations, while the degradation-based approach (IV) can only rely on extrapolating the current trend.

The ambition level is defined as the level of detail that is required in the maintenance decision making process

Define the Ambition Level

The second identified problem is the commonly observed mismatch between the ambition level of the company and the initially available data. Therefore, both a definition of the ambition levels (this subsection) and the data types is required. The ambition level is defined as the level of detail that is required in the maintenance decision making process. Therefore, it is important to consider the four aspects set out below.

1. Is predicting the assets life time on an individual basis required?
   - If this is not required, only a generic prediction can be made for a fleet or group of assets;
   - If individual predictions are required, this also means that monitoring of individual assets is required.
2. Should variations in usage of the assets be included?
   - If not included, maintenance will be based on calendar time;
   - Typical variations in usage to be included are operating hours, driven kilometres, start/stops;
   - If these variations are to be included, they must also be monitored or registered during operation;
3. Should variations in environmental conditions be included?
   - If not included, maintenance will be based on average conditions;
   - Operating the system at elevated temperatures, high humidity, etc. could lead to accelerated degradation;
   - If these variations are to be included, they must also be monitored or registered during operation;
4. Do the future conditions differ from the current or historical conditions?
   - If there is no difference, an extrapolation of a general trend can be made;
   - Otherwise, these expected variances have to be included in the prediction using a model.

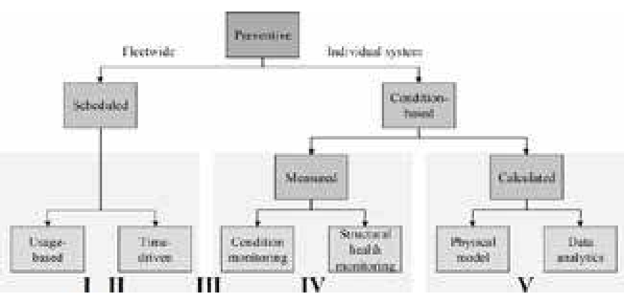

Figure 2. Relation between preventive maintenance policies and proposed types of MTs

Based on these four aspects, five different ambition levels (AL) can be defined, as shown in **Table. 1.** The decision scheme in **Figure. 3** then provides a guideline to select the appropriate ambition level.

Defining data types

The next step, that also follows from problem of gap between ambition level and initially available data, is defining the various data types used in maintenance. **Table. 2** shows four types of data that are required for the five maintenance approaches.

Mapping data inputs and ambition levels to the five maintenance approaches

The final step in solving problem is to map the various ambition levels to the required data types and link

Table 1. Types of prognosis: ambition levels

Type	Level of detail in maintenance decision making
AL 1	Insight in future behaviour of the asset or fleet considering static conditions
AL 2	Insight in future behaviour of the asset or fleet considering differences in usage
AL 3	Insight in future behaviour of the asset or fleet considering differences in usage and environmental conditions
AL 4	Insight in real-time deterioration of the individual asset and extrapolation into the future under constant conditions
AL 5	Insight in real-time deterioration of the individual asset and extrapolation into the future under largely varying conditions

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them to the preventive maintenance approaches. This will quickly reveal whether the chosen ambition level matches with the available data. Selecting the appropriate preventive maintenance approach is then proposed to be a trade-off between the available input and the ambition level. On the one hand, the ambition level determines the techniques that should be applied. On the other hand, the available data puts limitations to the applicable techniques. **Figure. 4** shows the relation between the ambition levels, the available preventive maintenance approaches and the required data types. The figure shows that with some maintenance approaches, several types of ambition levels can be achieved (i.e. reliability statics for AL 1 & AL 2). At the same time, the **Figure. 4** shows which data is required for each approach. For example, required inputs for 'analysis IV' are high-quality historic data (1), and condition- or health-monitoring data (4). Required inputs for 'analysis V sub A using a physics of failure model' are usage or load monitoring (2 or 3) data and condition- or health monitoring data (4). Only when these high-level data sources are available, an AL 4 prognosis is feasible. Note that the difference between V sub A and V sub B are the data requirements. A data model requires high quality historical data to train the algorithm. If this data is not available, the only other option is to use a physical model.

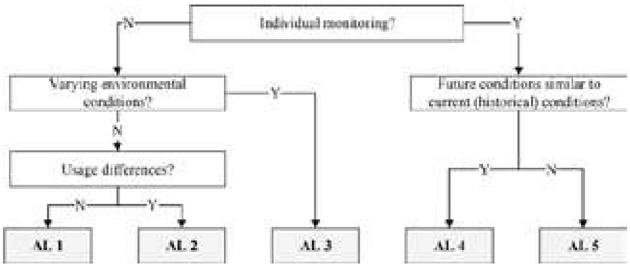

Figure 3. Guideline for the selection of the ambition level

Table 2. Types of data

Type of data:	Description:
Historical data:	This data can be gathered from technical knowledge, inspection and historical records of failures or costs for instance. We can differentiate between high and low quality historical data. High quality data includes information on historic usage, loads (including environmental stressors) or condition/health per group of systems (fraction of fleet, i.e. a specific unit or type). This information is collected by manual registration, e.g. logbooks or databases, instead of detailed monitoring.
Usage monitoring:	The process of acquiring operational data, e.g. running hours, mileage, or tons produced and/or process control data (e.g. Supervisory Control and Data Acquisition: SCADA). This preferably includes environmental data, consisting of measures of temperature and moisture for instance.
Load monitoring:	The process of acquiring loading data, e.g. temperature, vibration, humidity, strain or electrical current (Tinga 2010).
Health or condition monitoring:	The process of acquiring signs of imminent failure, e.g. vibrations, acoustics, temperatures, or data from oil analyses (all denoted *condition monitoring*) or data extracted from the measured (dynamic) system response to identify the presence and magnitude of damage in a system, denoted as *structural health monitoring*.

The process of acquiring signs of imminent failure, e.g. vibrations, acoustics, temperatures, or data from oil analyses (all denoted condition monitoring) or data extracted from the measured (dynamic) system response to identify the presence and magnitude of damage in a system, denoted as structural health monitoring

Business case

The final identified problem shows that it is difficult for the firm to prove the added value of the implemented maintenance approach. However, it is known that developing a business case is key for project success and it is observed that often a costly trial-and-error approach is followed in the implementation of CBM (Tiddens, Braaksma, and Tinga 2015). Moreover, for almost 30% of

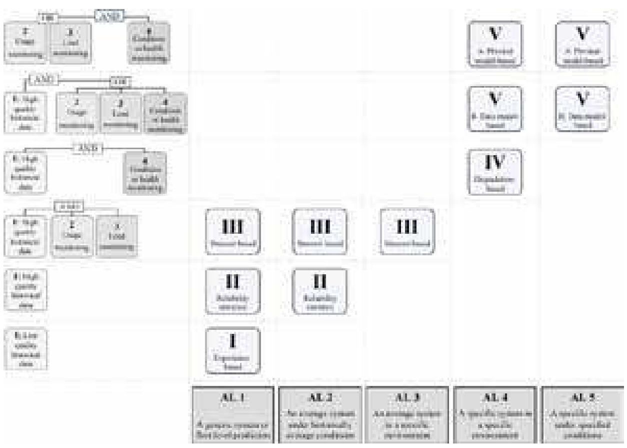

Figure 4. Mapping preventive maintenance approaches to the ambition levels and data types

industrial equipment CBM does not provide any benefit. Therefore, it is important to evaluate the investment in CBM in a structured way before the MT is actually selected. For techniques that are known to the company, or proven within the field, often a clear business case can be defined as reliable estimates of the costs and benefits can be made.

However, when more innovative techniques are developed, estimating the costs and benefits is difficult. Such a case often requires the costly collection of extra data for which sensors have to be acquired and installed. Moreover, the time before achieving the benefits is longer and therefore the benefits are more uncertain. In other work (Tiddens et al. 2017), developed a hybrid method to construct the business case for condition-based maintenance. This method shows that a justification should be composed of both a non-financial and a financial analysis. In case of innovative techniques, with their highly uncertain costs and benefits, a business case should be composed of non-financial elements. When the costs and benefits can be reliably estimated, a financial evaluation should be added to this business case.

Designing a method to select the appropriate maintenance technique

To offer decision-support for practitioners, a preventive maintenance approach selection framework is proposed in this section. This framework is based on the earlier discussions. The proposed framework is shown in **Figure. 5**

Either decision pull, based on the demand to achieve a certain ambition level as is shown in Figure. 6, or technology push, based on available and (possibly) worthwhile data

as a decision tree. The choice for a specific maintenance approach can be made via two starting points. Either decision pull, based on the demand to achieve a certain ambition level as is shown in **Figure. 6**, or technology push, based on available and (possibly) worthwhile data. Ideally, the selection starts via the decision pull starting point. This gives the company the opportunity to select the optimal maintenance technique (i.e. a selection that is not directly limited by the available data). After the ambition level has been determined, it is checked whether there is a match with the available data, as follows from initial solution 2B. The mapping (initial solution 2C) is then used to advise one of the five types of maintenance approaches. When there is a match between the available data and the ambition level, the framework will directly indicate the associated maintenance approach. The issue remaining then is that a business case should be made. When a positive business case can be made to invest in

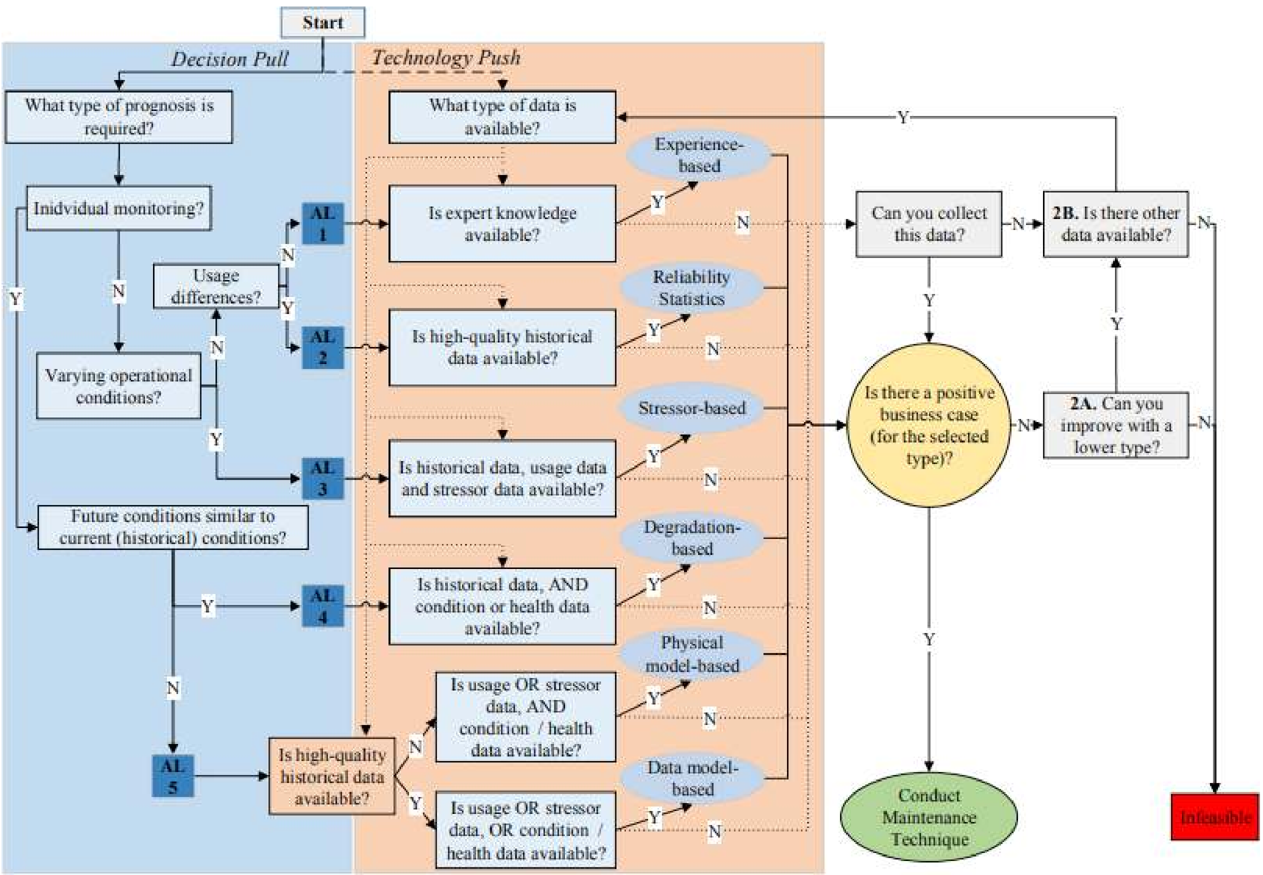

Figure 5. Proposed preventive maintenance approach selection framework

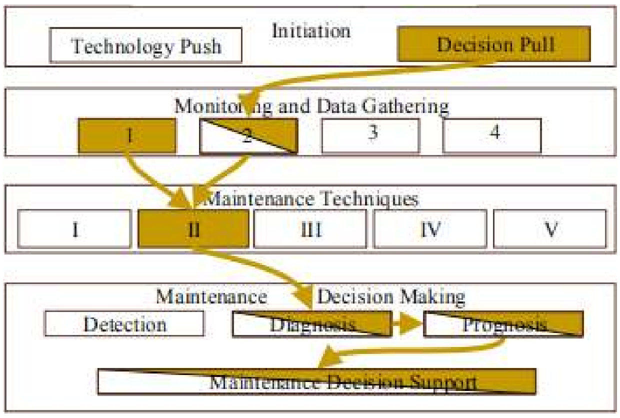

Figure 6. Support frame work

the maintenance approach for this asset, the selected approach can be conducted.

However, in practice there will quite often be a mismatch between ambition level and available data. The framework will then guide the user to a matching combination. When the required data is not available (for the selected ambition level), the first check is to investigate whether it is possible to start collecting this data. If so, again the business case should be checked. If not so, other data might be available. This leads the process to restart, but now from a technology push starting point. When starting from the technology push starting point, the available data is leading in the choice of the maintenance approach.

Therefore, the first step after selection (and getting advice for the associated maintenance approach) is to examine whether a positive business case can be made to continue with this approach. If the business case check results in a negative advice to continue, it should be evaluated whether improvements can be made with a lower or different type of data and associated ambition level. Note that starting from the technology push starting point (led by the available data) is a common approach

> *ECTM is the process of using measured characteristics (i.e. compressor speeds, inter-turbine temperature and fuel flow) during specified conditions (i.e. vessel speed, sea condition outside air temperatures) and comparing these to predicted values to provide confirmation of engine*

in many companies. However, it is somewhat dangerous since the definition of the ambition level is neglected. This could lead to a positive business case for the selected data type and maintenance approach, but the company could discover at some stage that this approach does not perform as expected. Explicitly defining the ambition level beforehand and incorporating that in the selection process, as is done in the framework, could prevent such a situation.

Case study: Engine condition trend monitoring for ship

For the marine propulsion systems, assume a fixed-interval preventive maintenance policy has been applied successfully in the past. Then recently the Engine Condition Trend Monitoring (ECTM) technique has become available. ECTM is the process of using measured characteristics (i.e. compressor speeds, inter-turbine temperature and fuel flow) during specified conditions (i.e. vessel speed, sea condition outside air temperatures) and comparing these to predicted values to provide confirmation of engine. To reduce the maintenance costs, the department is investigating whether it is both economically and technically feasible to apply a condition-based maintenance approach using ECTM. Then the structure shown in **Table. 3** assists in decision making process. For this case there is a match between the ambition level and the data available through the

Table 3. Support frame work

Step in framework	Result & explanation
Starting point	Decision Pull - aim to reduce maintenance costs by conducting condition-based maintenance
Type of data available	- Expert knowledge is widely available within the department - Usage and loads data (sensors on ship measure ship speed, sea condition, airspeed, outside air temperatures and inter-turbine temperature etc)
Ambition level	- Monitoring of individual engines - Operated in varying environmental conditions - Future conditions assumed to be similar (might be different, not included yet) ◊ Ambition level 4
Match ambition level and available data?	Yes - AL 4 requires condition monitoring data (available) Data required for physical model-based approach (AL5) is also available
Positive business case?	Yes - financial justification conducted (Tiddens et al. 2017) (total lifecycle costs of ECTM lower than corrective maintenance or fixed-interval preventive maintenance)
Conduct MT	Advice: apply a degradation-based maintenance approach. Organization will further develop ECTM, set ambition level is satisfied

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new technology (ECTM). The framework confirms that this degradation-based maintenance approach is the appropriate approach for this company.

Conclusion

Maintenance has evolved in the last decades from merely reacting to failures, through preventive replacements at fixed intervals or based on visual inspections, towards automated methods that continuously inform about the asset's future state. Many different maintenance policies are available now, ranging from the traditional corrective maintenance to more advanced policies like condition-based or predictive maintenance. Moreover, many methods and techniques for monitoring and inspecting assets, analysing data or predicting remaining useful life have been developed. The proposed framework can help practitioners reduce the costly trial-and-error-process in applying a preventive maintenance approach. Therefore, selecting the optimal approach for maintaining a specific asset has become easier for the asset owner.

Acknowledgement

This is an academic work performed during the final year of Professional Doctorate in Engineering (PDEng) program at the University of Twente (collections during literature review process, can also be viewed as condensed version of [1]). As this PDEng is also an industrial project I also express my gratitude to Prof. Tiedo Tinga who headed Dynamics based maintenance (DBM), for his guidance and to sustain funding from industrial partners to support this work. The idea to introduce this work in to maritime sector was first proposed by researcher Filippos Amoiralis (based on extensive interviews with stake holders), who worked in DBM group in the year 2015. This work is under further development now.

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About the Author

Prabu Duplex had sailed as a marine engineer between 2005- 2013. He graduated from a Professional Doctorate in Engineering (PDEng) programme at the University of Twente, in the Netherlands. He also worked in a research group called "Dynamics Based Maintenance (DBM)" which actively focuses on developing innovative predictive maintenance methods for a wide range of industries. His work involved in developing physics based mathematical models to predict the life time of diesel engines components in maritime propulsion systems. He also has a Master's degree in Naval Architecture. Presently, he is looking for a career in design or research activities in naval, wind, offshore or predictive maintenance domains.

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Beyond Climate Change: A Model of Sustainable Development for the Maritime Industry

D. G. Adkins

Abstract

Recent discussions on sustainable development in the maritime industry have focused on climate change, emissions reduction, and future fuels. While vital for global trade and climate management, these topics are only part of the broader sustainable development agenda. The United Nations Sustainable Development Goals (UN SDGs) highlight the need to expand this conversation.

Through a series of interviews, this study aims to develop a sustainable development model tailored to the maritime industry. Defining the maritime industry, and contextualising sustainable development to the sector provides significant challenges. The industry's diversity complicates any definition as it encompasses shipping, maritime services, shipbuilding, education, equipment manufacture, offshore supply, recreational boating, fisheries, coastal tourism, marine mining, and offshore energy.

The results show a model that can be applied to the industry in order to address key sustainable development challenges. Key areas that can be incorporated into business strategy have been identified and explained.

Keywords: Sustainable Business Model; Maritime Business; Social Sustainability; Environmental Sustainability; Responsible Management.

Introduction

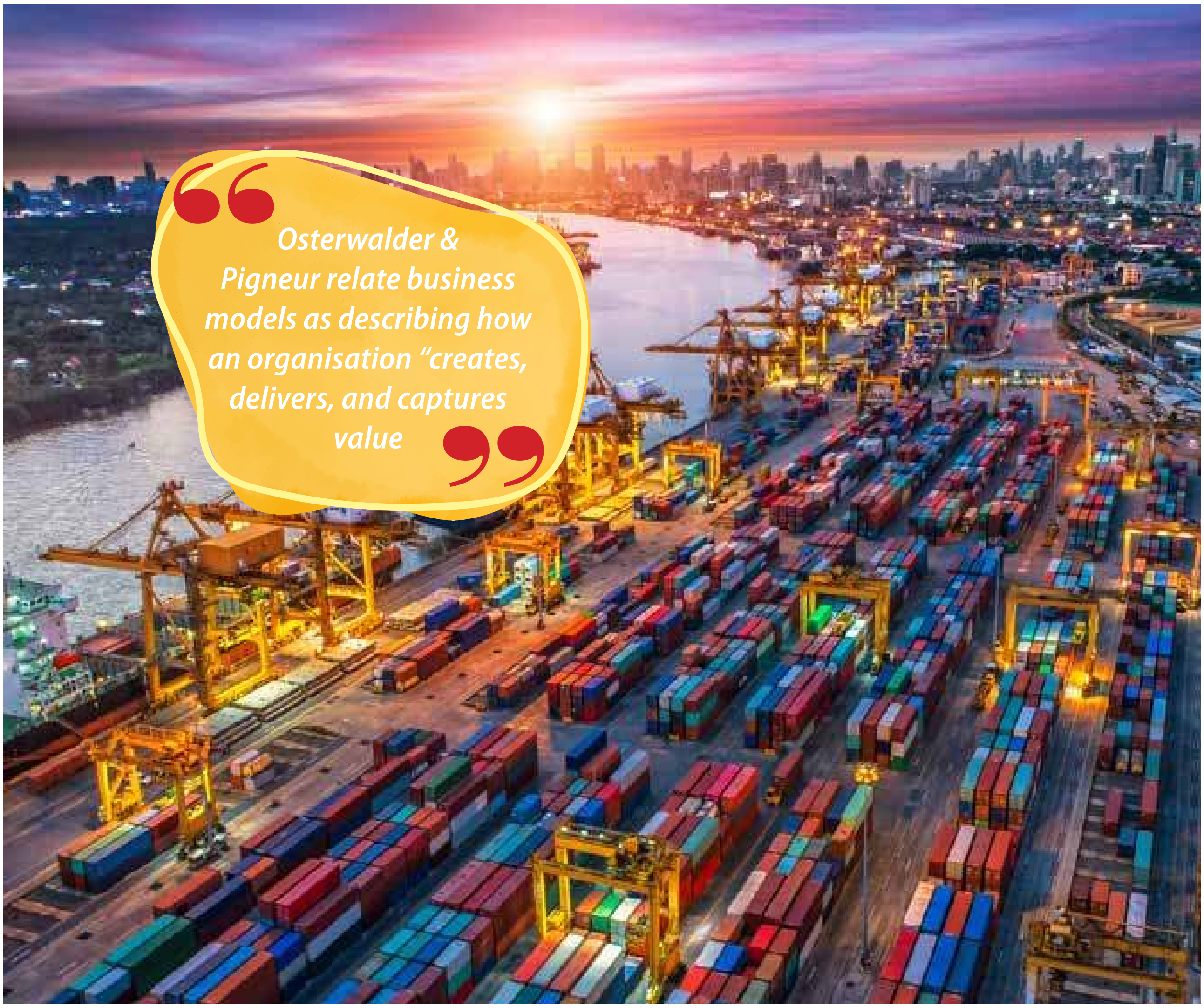
In recent years discussion of sustainable development within the maritime industry has tended to focus on topics relating to climate change, minimising emissions, and the development of future fuels. However, whilst critical to the future of global trade and to managing climate change, these form only one part of the wider sustainable development agenda. A cursory glance at the seventeen United Nations Sustainable Development Goals (UN SDGs) highlights the need to widen the debate.

This study aims to develop of model of sustainable development that is appropriate for the maritime industry. Within that (relatively) straightforward aim lie a number of challenges:

- what does sustainable development mean for the maritime industry?
- what constitutes the 'maritime industry'?
- what is the purpose of the model?

Sustainable development can be characterised by the UN SDGs, but even using that as a framework, sustainable development can mean different things to different people, as well as being both an ongoing process and as a goal in its own right.

Alongside this, defining the maritime industry can be challenging, particularly as "*Maritime business is exceptional, diverse, and peculiar*" [1]. Clearly shipping, maritime business services and shipbuilding/repair are core aspects of the industry, but the maritime industry is broader. It includes education and training; equipment manufacture and repair; offshore supply; recreational boating; fisheries and aquaculture; coastal/marine



tourism; marine minerals mining; and offshore energy. For the purposes of this research, the term 'maritime industry' is used to represent all of the aspects.

Turning to the purpose of the sustainable development model, one has to consider the overall aim of business models; Osterwalder & Pigneur relate business models as describing how an organisation "creates, delivers, and captures value [2]." Recent years have seen a growing link between business models and sustainable development as a result of the latter taking on greater corporate significance. Sustainable business models must therefore enable organisations to understand their value proposition, along with focus on new ways of working, infrastructure development and growth across environmental and social aspects.

Defining Sustainable Development

Sustainable development emerged to address global environmental and social concerns, encapsulated in the 'Brundtland Report' as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [4]. This concept has historical roots, with early examples of resource protection dating back to the 17th century, highlighting longstanding concerns about sustainable resource use.

Sustainable development encompasses various definitions but generally involves the interplay between environmental issues, socio-economic problems, and the need for a sustainable future. It is viewed as both an evolving process and an ultimate goal. Reference [5] (2003) proposed a taxonomy to mitigate ambiguities in defining sustainable development, categorising goals into aspects to be sustained (e.g., nature, biodiversity, ecosystems) and aspects to be developed (e.g., people, economy, community, society).

Although historically the notion that businesses exist solely for profit, as argued by Reference [6], this has been challenged, with recent perspectives recognising that business viability depends on healthy ecosystems and stable societies. For this study, the Brundtland Report's definition of sustainable development is adopted.

The Triple Bottom Line

Sustainable development extends beyond economic considerations, incorporating social and environmental

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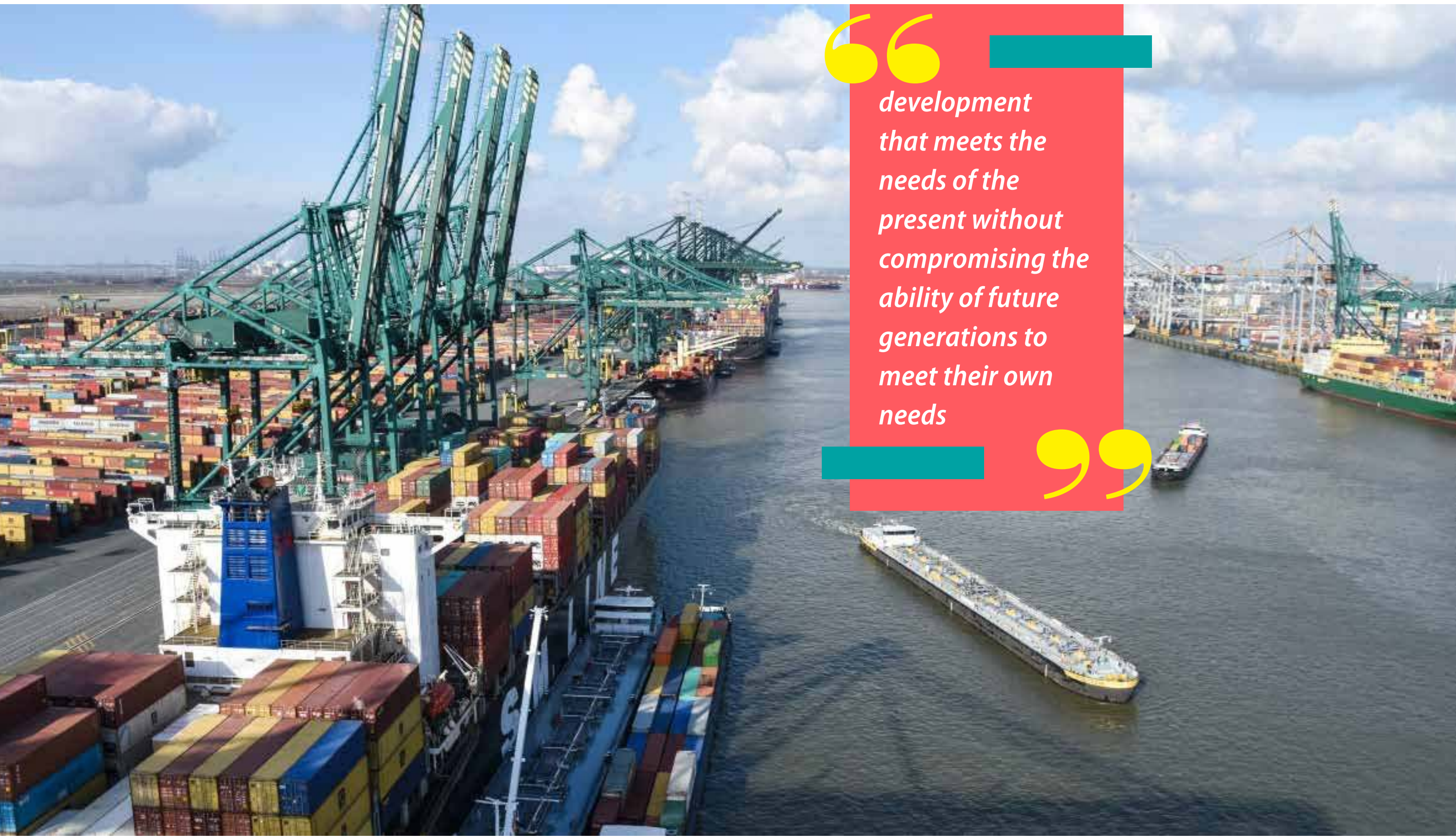

> *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*

dimensions. The Triple Bottom Line (TBL), popularised by [7], frames these dimensions as interconnected pillars essential for sustainable development. This approach argues that a company's success is measured not just by economic strength but also by social and environmental performance.

The TBL serves as both a tool for improving organisational functions and a reporting mechanism, providing early warnings to react to stakeholder changes and mitigate impacts. This framework suggests that development goals must be socially focused, respect environmental conditions, and be economically feasible [8].

Economic Sustainability

Economic sustainability is defined as the optimal management of resources to achieve stable growth. It involves maintaining economic growth, increasing customer numbers, fostering innovation, and supporting social and environmental issues. This requires considering financial performance, strategic planning, and innovative practices to ensure long-term viability.

Environmental Sustainability

Environmental sustainability focuses on maintaining natural capital, which includes both critical and renewable resources. This involves ensuring that resource use meets current and future needs without compromising ecosystem health. Organisations must use environmental knowledge to inform decisions, minimise waste, and manage operations within an environmental management system.

Social Sustainability

Social sustainability encompasses aspects like social capital, cohesion, inclusion, and community engagement. It involves ensuring equitable access to services, intergenerational equity, community ownership, and political participation. Organisations must consider skills development, stakeholder engagement, and community participation to achieve social sustainability.

Sustainable Business Models

Business models articulate how firms deliver value to customers through interrelated functions and external relationships. These models have evolved to incorporate sustainable development, reflecting changes in business practices and organisational goals. Sustainable business models integrate value propositions, financial models, customer interfaces, and business infrastructure, emphasising long-term focus, resource sharing, and stakeholder engagement.

Interest in linking business models with corporate sustainable development has grown, recognising sustainable development as a strategic goal that requires structural and cultural changes within organisations. External drivers like legal changes and customer pressure, alongside internal drivers like personal beliefs and

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efficiency needs, drive the pursuit of sustainable business models.

Sustainable Maritime Business Models

The maritime industry has limited literature on sustainable business models, often focusing on specific outcomes rather than holistic approaches. However, some studies examine port sustainable development, proposing frameworks for managing environmental impacts and developing sustainable practices.

Reference [9] developed a Port Sustainability Management System for smaller ports, aligning with the value proposition, customer interface, and business infrastructure aspects of sustainable business models. Although financial modelling is less represented, the system's focus on asset longevity and maintenance provides a base model adaptable to wider maritime contexts.

Figure. 1. shows the *a priori* themes developed from the literature; these themes formed the basis of the interviews which sought to confirm and expand themes for the final model.

In summary, sustainable development integrates economic, environmental, and social dimensions, with business models evolving to reflect these goals. The maritime industry, particularly ports, demonstrates specific sustainable development needs that can inform broader applications. Sustainable business practices ensure long-term viability by balancing profitability with environmental stewardship and social responsibility.

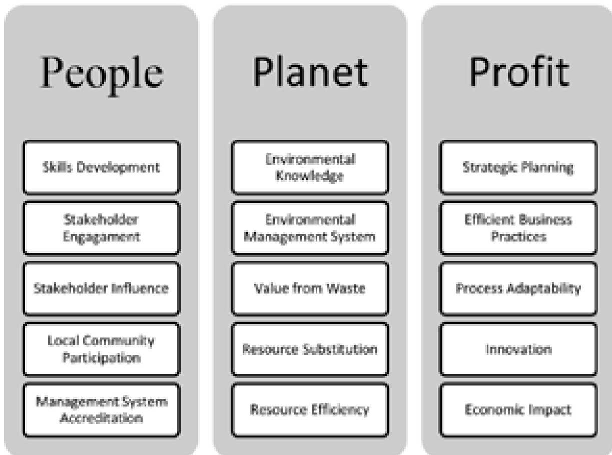

Figure 1. a priori Themes of Sustainable Development
Source [3]

Methodology

Interview subjects were selected from those deemed to be involved or have an interest in sustainable development within organisations across the maritime industry in the UK.

Table 1 shows the list of participants.

Thematic Analysis enables the analysis of different types of data, varying sizes of datasets and the production of theory-driven analyses [10]. This is of particular importance given the need in this study to

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Table 1. List of Interview Participants

Interviewee	Position	Sector
A	Harbour Master	Port Authority
B	Sales Manager	Engineering
C	Head of Marine Operations	Shipping & Engineering
D	Director	Education
E	Chief Executive	Maritime Business Services
F	Director	Maritime Business Services
G	Partner	Maritime Legal Services
H	Owner	Shipowner
I	Senior Business Developer	Cultural Organisation
J	Chief Executive	Cluster Practitioner
K	Legal Director	Maritime Legal Services
L	Chief Executive	Cluster Practitioner

Source [3]

synthesise literature and interview data to produce a theory-driven sustainable business model appropriate for the diverse nature of the maritime sector.

Template Analysis as a Form of Thematic Analysis

As a form of Thematic Analysis, Template Analysis has been used extensively in business, management and organisational research [11] [12] [13]. Reference [14] identifies two key advantages of using template analysis; it can be particularly flexible to meet the needs of the research, and it is argued to work well in research examining the views of differing groups in an organisational context. Template Analysis is regarded as a flexible approach that can be used across a range of philosophical positions within qualitative research [13]. As a result, there is no one prescriptive method, although there are general principles; these steps, based on [15] [13] [16] were followed:

Stage 1: Develop *a priori* Themes

a priori codes, based on established literature, range from 'hard' to 'soft' themes (King and Brooks, 2017). 'Hard' themes are clearly defined, while 'soft' themes are potential areas of interest. This study focuses on 'harder' themes. Two considerations in using *a priori* themes are to remain open to new themes and to adjust or discard predetermined ones if needed, to maintain research validity [15] [17].

Stage 2: Data Familiarisation

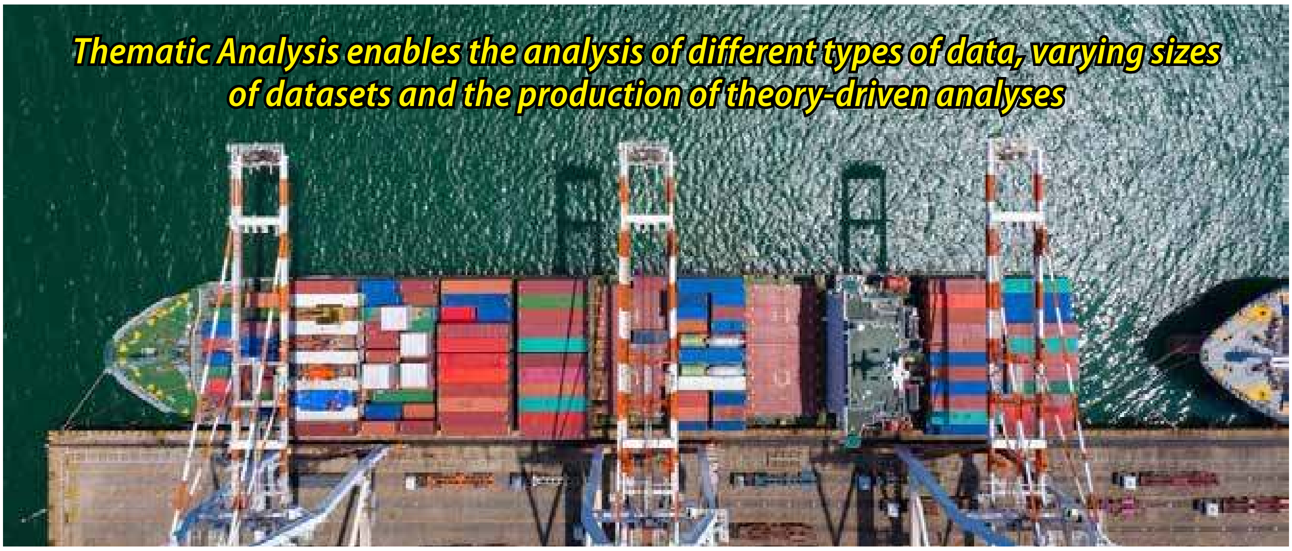
This stage aims to immerse the researcher in the data through repeated reading and listening; it goes beyond data familiarisation, involving more analytical and critical reading [18]. While some analysis occurs, it is less formal and precise than later stages, and outcomes from this stage were not solely relied upon.

Stage 3: Preliminary Coding

This stage involves identifying data relevant to the study's aims, objectives, and research questions, similar to most thematic analysis methods [17]. The coding process starts with 'complete coding,' identifying anything of interest [18]. Potential themes, alongside *a priori* themes, are identified at this stage.

Stage 4: Define Initial Coding Template

This stage focuses on identifying and reporting patterns in the data, with emphasis on the meaning of patterns rather than their frequency. Saliency analysis, introduced by [19] and discussed by [18], emphasises the importance of infrequent items. Unlike other thematic analysis methods, template analysis often uses a data subset for initial coding [17]. However, this study used the entire data set for preliminary coding, enhancing validity by ensuring



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no emergent themes were overlooked and allowing for template modifications.

This study employed hierarchical coding to develop the initial coding template. This process groups similar codes into higher-order themes, typical of template analysis [17]. Hierarchical coding aligned well with using *a priori* themes, which were organised as top-level and sub-level themes.

Stage 5: Applying and Developing the Template

This stage typically applies the initial template to new material. Since the entire data set was used to develop the initial template, the template was reapplied to the same data with a different perspective. This iteration confirmed the template, ensured inclusion of relevant material, and verified the relevance of previously included material.

Stage 6: Finalise Template

Reference [17] identify three aspects of final interpretation and presentation: examining theme patterns, prioritising themes, and exploring connections. Analysing patterns can offer insights and justify further examination. Listing and summarising findings are crucial, particularly in this research, as the qualitative phase justified the themes in the quantitative survey. Understanding theme connections can lead to revising theoretical models, which is significant for the development of the quantitative phase.

Findings

A comprehensive literature review enabled the development of core *a priori* themes as required by the Template Analysis approach. Interview topics were based around these themes with the aim of confirming, revising or removing them.

Perceptions of Sustainable Development

Each interviewee was asked to give their perception of sustainable development. There was consensus that sustainable development should be viewed as growth that does not deplete or destroy the resources or environment needed to sustain itself, although others acknowledged that sustainable development may mean different things to different people.

Many of the responses focused on the long-term survival and growth of the organisation, for example "ports that aren't sustainable wither and die" (Interviewee A). Sustainable development was described as the ability to operate within one's financial means, ensuring that income and expenditure are balanced with a small surplus. Environmental concerns were included, with emphasis on approaches being environmentally conscientious, aiming to generate surplus funds that can be invested in long-term infrastructure and maintenance for the benefit of both current and future stakeholders. The long-term view was further reinforced. It should not be viewed as a short-term, profit-driven venture but rather one that

ensures longevity, integrating environmental and social responsibilities for long-term benefits.

It was argued that in a business context, sustainable development encompasses the wellbeing of staff, the environment, and the positive impact of their products both locally and internationally. Sustainable development was linked to maintaining good client relationships and ensuring client satisfaction. Furthermore, sustainable development was closely associate with trust, emphasising the importance of long-term relationships and partnerships. Sustainable development is about ongoing collaboration and mutual trust rather than one-off transactions.

The social aspect of sustainable development was highlighted by some interviewees: "…it means wellbeing of staff…" (B); "…responsible development as well as the social aspects…" (G), with a particular focus on skills from J: "…the big challenge for the maritime sector is skills…"

The discussions continued by examining the pillars of sustainable development that form part of the Triple Bottom Line proposed by [7]. For this study, these pillars were referred to as the profit, people, and planet dimensions of sustainable development.

Profit

Issues around profitability and long-term economic viability dominated the initial discussions on sustainable development; "any business that is not profitable is not sustainable" (C) and efforts must "be economic at the end of the day" (F).

Whilst those issues were the most significant, there was discussion of how to embed sustainable development in to strategic planning, and the need for innovation to support business growth.

Table 2. Summary of Data Analysis

Theme	Sub-theme	Key Findings
People	Skills Development	Skills are critical Staff development and engagement with educational institutions Long-term issue
	Stakeholder Engagement	Engagement with wider region Provide benefit to stakeholders Stakeholder involvement in development issues
	Stakeholder Influence	Increasing awareness of industry issues Promoting the maritime industry Providing benefit
	Local Community Participation	Contributing to region Engagement with educational institutions Engaging with local community
	Management System Accreditation	Open dialogue through relationships Considers different factors Long-term view of business development
Planet	Environmental Knowledge	Operations take environmental considerations into account Exercising diligence in decision-making Collaboration to develop knowledge
	Environmental Management System	Operating in a conscientious way Informing decision-making Formal recognition not significantly important
	Value from Waste	New ways to use waste by-products Collaboration to solve common problems Proximity important to achieve this
	Resource Substitution	Developing renewable energy sources through collaboration Knowledge creation and diffusion to meet challenges Lower recognition in business service firms
	Resource Efficiency	Sharing assets Integration of systems Lower recognition in business service firms
Profit	Strategic Planning	Sustainable development in business plan Key part of sustainable development Meeting future needs
	Efficient Business Practices	Sharing best practice Closer integration Contributes to new ways of working
	Process Adaptability	Ability to meet changing regulations
	Innovation	Significant challenge to the maritime industry Link to academic and R&D institutions Environmental focus
	Economic Impact	Remaining in business Contribution to region through wages, taxation and indirect spend Financial management critical to sustainable development

Source: [3]

People

The people, or social dimension of sustainable development refers to the impact organisations have on their employees, workers throughout their supply and value chains, customers, stakeholders, and the communities in which they operate [20]. Among the interviewees, the people aspect of sustainable development was seen as crucial: "you need the right people. You need the right skills. You need the right experience. You need to keep the experience which exists in the UK going" (E).

The broader training role of firms was discussed: "the training and skills issues are self-evident because of the way they've built their own training school... and there's a real engagement between skills gaps and employer-led training" (F); with retaining knowledge in the region being important "because it creates a maritime centre of excellence and if a sustainable maritime centre of excellence is established then the benefits for the whole region are enormous" (G).

While the people dimension was dominant, there was some discussion about maintaining the customer base and staying relevant to customer needs (A); supporting the community in which they operate (C); and supporting local educational providers (K).

Planet

Of the three pillars, the planet pillar was the least developed. This may be partly due to the types of businesses the interviewees represented, where environmental issues were considered less pertinent. Knowledge played an important role in one interviewee's experience, where the firm was involved in the "sustainable development of the Arctic; putting regulations in place that will make it safer for seafarers, protect the indigenous community and help prevent pollution" (G).

Some highlighted the importance of environmental issues: "...it's done with due regard to the environment..." (A); and that it "...doesn't destroy the resources or environment that it requires to sustain itself..." (E). E emphasised the environmental aspect of sustainable development further: "It is an environmental terminology" and viewed the application of sustainable development in the maritime business services sector with some

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This course is principally intended for candidates for certification for basic training for oil and Chemical tanker cargo operations as specified in section A-V/1-1 para 1 of the STCW Code as amended.

On successful completion of this course, candidates will be qualified in accordance with regulation Section A-VI/1 of the STCW code for Seafarers, 1978 as amended and will be eligible to carry out the assigned specific duties and responsibilities related to cargo or cargo equipment on Oil and Chemical Tankers

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reservation: "I don't think sustainable development's a useful term in this context… you know, I mean, you know these are service businesses… they don't destroy resources that they need. I mean it just doesn't work like that" (E).

In summary, perceptions of sustainable development demonstrated the importance of sustaining and developing the business as a central tenet of sustainable development. Other related activities were generally seen as secondary to, or supportive of, staying in business. **Table. 2** summarises the key findings from the interviews.

Conclusion

Whilst decarbonisation and climate change have dominated much of the discussion around sustainable development across the maritime sector in recent years, the sustainable development agenda is much Smore extensive. With sustainable development meaning different things to different people at different times, firms can find meaningful engagement with the topic difficult. Implementing a sustainable business model, focusing on the people, planet and profit pillars of sustainable development can provide a useful tool for maritime firms to develop their sustainable development strategies.

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Sustainable Shipping In The Climate Change Scenario – A Technology Initiative

J. Prince Prakash Jeba Kumar, S. Ragumaran, Vijaya Ravichandran, B. K. Jena

Abstract - Sustainable development is not just about climate change but about effectively meeting present needs without compromising the ability of future generations to meet their own needs. This paper discusses a port-based eco-friendly filtration system, a crucial step towards this goal. It effectively balances economic growth, social well-being, environmental protection and addressing climate change impacts. In the shipping industry, ballast water discharges significantly threaten marine biodiversity through the spread of Invasive Alien Species (IAS). This system envisages avoiding the entry of planktonic forms and IAS, which provide ecosystem service of avoiding sediment formation in ballast tanks, reduces the coat of chemical and energy usages of ballast water treatment system and 99% efficiency of achieving D2 standards of International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM), expected to enable easy policing of treated water for quality assurance. Introducing a port-based eco-friendly filtration system envisions clean water and sanitation, decent work, responsible water consumption and production and more. This technology is a preliminary initiation towards securing a sustainable and resilient future for marine ecosystems.

Keywords: Subsurface intake system; Eco-friendly technology; port-based ballast water treatment system; Invasive Alien Species

Introduction

Sustainability transforms our societies and economies into more inclusive, resilient, and workable. It requires sustainable consumption and production patterns, biodiversity and ecosystem protection, sustainable cities and infrastructure development, and universal access to essential health care and education services. These efforts ensure a liveable planet for current and future generations.

Shipping, a vital component of global trade, is crucial in sustainability. The industry accounts for 80% of world trade and has been essential for trade since 4000 BC. The Maritime Report 2023 highlights measures such as decarbonisation to protect the marine environment and biodiversity and improved restrictions on invasive alien species from ballast water, marine litter, plastics and the quality of antifouling paint to ensure environmentally friendly and fair cargo transition [1].

Popular available technologies help reduce unplanned issues such as Invasive Alien Species (IAS) and the impact of antifouling paint, etc. However, they also generate process waste that must be disposed of by statutory norms. It is envisaged that developing technology with a renewed focus and changing processes without harming marine ecosystem components will ensure sustainable development. In this context, we will discuss one such technology for preventing the introduction of invasive alien species through ballast water.

Given its significant impact on global trade, the shipping industry bears a weighty responsibility in this journey toward sustainability.

Ballast water and bio-invasion

It represents critical concerns within the maritime sector, as the inadvertent introduction of diverse organisms into foreign aquatic environments through ballast water discharge poses a significant threat to local ecosystems. The ramifications encompass considerable ecological and socioeconomic implications. The disruptive influence of invasive species within marine ecosystems compromises sustainability, impacting indigenous communities reliant upon these environments. Predation, ecological disturbance and disease propagation are among the adverse effects perpetuated by translocated species, further affecting the community and population ecology. Notably, invasive species interferences can significantly compromise food webs, water quality, and disease transmission, amplifying their socio-ecological impact. Indigenous populations, profoundly ingrained with the natural biodiversity, wildlife, and aquatic domains, encounter formidable challenges when invasive species disrupt the availability of native marine species.

Consequently, the viability of local food resources and fisheries is endangered, significantly impacting these communities. The translocation of non-native species via ballast water transportation constitutes a pressing concern within the maritime industry, as underscored by the recent incursion of South America's Charru mussel (*Mytella strigata*) into Pulicat Lake, a Ramsar site on the Chennai Coast in India. This invasive event has garnered Indian national attention, highlighting the urgency of addressing this matter. Ascertaining the requisite treatment of ballast water and the efficacy of associated technologies demands careful consideration.

State of ballast water treatment technologies

The Ballast Water Convention of 2017 mandates the installation of a ballast water treatment system for most trading merchant vessel categories. Two primary classifications of treatment systems, onboard and ashore, are utilised, with current designs predominantly focused on shipboard applications. Support measures, such as sampling and testing, surveys and risk assessment, have generally been shore-based. Onboard methods encompass physical separation techniques, including filtration and hydro cyclones and disinfection processes, such as UV irradiation, ozonation, heat shock and chemical biocides. Most available systems combine one or more methods [2,3, 4]. The adoption of treatment protocols typically occurs during ballast water uptake (57%), discharge (34%) and sea passage (10%) [5]. The costs of these systems, both capital and operational, exhibit variability based on the employed methods and flow rates. Ongoing development and testing of promising technologies aim to attain higher treatment standards in the future. According to the International Maritime Organization (IMO) regulations, ships must adhere to an approved Ballast Water Management Plan and treat their ballast water with available technologies to meet specific standards before discharging it by 8th September 2024.

Nonetheless, commercially available technologies come with significant costs. Several technologies exhibit limitations, such as the filtration method being prone to frequent blocking and necessitating filter backwashing and the hydrocyclone-based separation technique showing inefficiency in small organism separation. Various disinfection methods experience shortcomings, including UV radiation being impacted by macro-organisms in the ballast water and electro-chlorination releasing total residual oxidant to the environment [6]. Finding practical means to ensure compliance with stringent IMO standards remains a key challenge despite the evolution of these technologies being primarily driven by existing technical capabilities aimed at eliminating invasive species. It is crucial to minimise ecological disruption and harness natural forces to remove alien species effectively To achieve sustainability.

> *"It is crucial to minimise ecological disruption and harness natural forces to remove alien species effectively To achieve sustainability"*

Sustainable technology for ballast water treatment

A paradigm shift of conceiving a problem, designing technological solutions and implementing methodology was considered for sustainably treating ballast water. Any technology implementation for solving problems in the ocean needs to be considered holistically, as most of the Earth's surface is covered by its oceans, which contain a remarkably varied set of ecosystems. These oceans are crucial for controlling our climate, offering nourishment for numerous species and maintaining the overall well-being of the planet. Regarding invasive species, selective elimination of IAS might be limited, but technological intervention should minimise the disturbance to marine ecosystems. The available technologies intend to eliminate IAS without purging phytoplankton and zooplankton, keystone species of the marine food web that cause significant disturbances to dynamic marine ecosystems. Seawater intake industries also augment it and marine pollution causes synergistic effects and aggravates the problem. The thrush holds signals expressed by the marine ecosystem in the form of harmful algal bloom and reduction in capture fisheries as the juveniles are planktonic killed during seawater disinfection, apart from the detrimental effects of IAS from shipping ballast. The shipping industry has to face the problem of sedimentation in their ballast tanks, and the seawater

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intake system of coastal industries was required to cope with the issue of pipeline stalling by biofouling, entrainment and impingement perpetually. It requires designing efficient technologies and equipment that cause less harm to the environment. Hence, harnessing the technology of extracting filtered seawater from subsea aquifers was envisioned. **A seabed bore at 1.5 m water depth started yielding 99% plankton-free filtered seawater at a pilot scale test system at the NIOT Nellore campus and the results were published.** The same was repeated in the laboratory setup, recording the removal of 99% of planktonic organisms. The filtered particles were of 20 to 200 mm size represented by phytoplankton and zooplankton against the BWM D2 standard desired size class of equal or less than 50 mm size and >10 number viable organisms were permitted to be discharged into the sea after ballast water treatment. Various bore methods to extract seawater are available on a commercial scale (**Figure 1**). They

Seawater intake industries also augment it and marine pollution causes synergistic effects and aggravates the problem

effectively produced organic matter-free water for desalination plants worldwide in a restricted manner. It can be adopted as a shore-based ballast water treatment system with the advantages of sediment-free ballasting for shipping in ports with polluted waters and plankton bloom situations, enabling efficient onsite ballast water quality management. The boring seabed causes very minimum benthic ecosystem disturbances and a few centimetre-thick topsoils are dredged and spread to nearby areas, preserving most of the benthic organisms during the drilling and construction phase. The problems of killing microbiota, including planktonic forms, were totally curtain, leading to considerable savings in energy, a critical recurring expense of onboard ballast water treatment machinery and the avoidance of harmful chemicals for disinfection. Hence, the sub-seabed boring system produces filtered seawater without waste and with minimum maintenance cost. A port system model plant was conceived, published elsewhere and adored in the public domain magazines [7,8]. However, this technology needed a natural sandy-silt sea floor for its effectiveness. The clayey sea bottom ports preferred to use the sea bed gallery system where sandy soil media shall be spread artificially in the waterfront foreshore areas of seaports and necessary piping systems buried, which yields 1,50,000 m^3/d of filtered seawater at Fukuoka, Japan **(Figure 3).** A sea bed gallery was envisioned even in the case of ports with little space for making a sea bed gallery system. However, Ports with naturally high suspended solid content in the water column have been considered for utilising this technology. The basic problem of the non-availability of sandy soil can be brought in through an artificial system mimicking a natural aquifer was trailed [9]. Achieved 65% filtration efficiency in a horizontal artificial aquifer developed at the test pond at the waterfront facility available in NIOT Chennai campus, as depicted in **Figure 3**. The problem of sand saturation

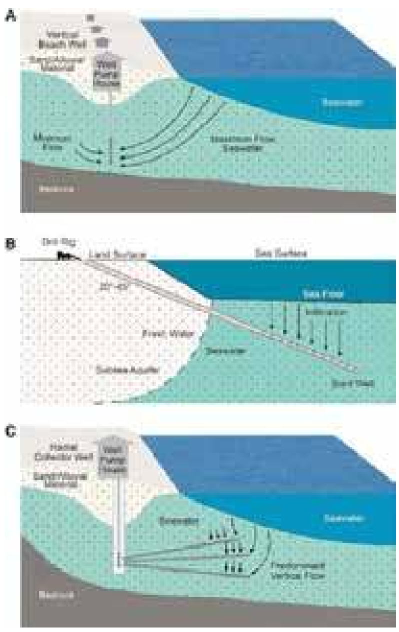

Figure 1. Different sub-seabed bores

A. Conventional vertical bore well located near tidal water (or a beach),
B. Angle bore well that can be constructed at some distance from the shoreline,
C. Ranney bore well that would need to be constructed on the beach

Figure 2. Seabed gallery system

Figure 3. Artificial aquifer developed at NIOT campus

(clogging of pores in the sand column by suspended matter) by algal organic matter was nullified by the grazing of fish species, demonstrating an ecosystem service utility in the system. The filtered water-yielding capacity is also promising. However, this plant suffers from sandblasting and loss of sand compaction in the vertical container, reducing filtration efficiency **(Figure 4).** Hence, a tube-in-tube method for the sand column has been proposed to utilise the water pressure to keep the soil compacted and avoid sandblasting. The miniature plant developed at the laboratory is depicted here **(Figure 5).** This miniature plant is able to produce 99% plankton-free water for 26 days and is saturated (not producing filtered water at normal flow rate) afterward. Suppose the design is executed in the field by utilising the ecosystem service of fish foraging in the ex-situ condition. In that case, it will yield the expected filtration for a long duration. Hence, it will be a sustainable technology for ballast water filtration by allowing plankton and fish for future generations.

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Consequences of technology adoption

The shipping industry faces challenges with the time it takes to fill ballast water tanks compared to using sea chests and the cost of filtered water. These issues can be addressed by reducing production costs and loading the required volume of water in the port in conjunction with regular port activities. This port-based ballast water loading method will help decrease sediment build-up in the ballast chamber and associated pipelines. Ports with naturally high suspended sediment loads can also benefit from this approach. Implementing this port-based treatment system will also enable better management of ballast water quality. Moreover, it aligns with the Sustainable Development Goals (SDGs) by providing a better work environment (SDG 8), improving water quality (SDG 6), responsible consumption and production patterns (SDG 12), and protecting marine life (SDG 14).

Conclusion

The economic costs resulting from the impact of invasive alien species on the ecosystem alone amount to US$137 billion in the United States [10]. Various countries will face significant economic implications, and effective technologies will be necessary to address this issue. Embracing sustainability and eco-friendly practices is crucial, and it requires a renewed focus on adopting innovations and pursuing further improvements. However,

Figure 4. Typical Sand blasting

Figure 5. Proposed Tube in Tube system

Moreover, it aligns with the Sustainable Development Goals (SDGs) by providing a better work environment (SDG 8), improving water quality (SDG 6), responsible consumption and production patterns (SDG 12), and protecting marine life (SDG 14) the battle against bio invasion is a complex and ongoing challenge that necessitates a combination of effective regulation, innovative technology and international cooperation. This highlights the importance of remaining vigilant and acting in the face of unseen invaders.

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Advancements in Marine Engineering

Atharva Bhoite , Harsh Soni, Krishna Seth

Abstract

The global shipping industry stands at critical crossroads, grappling with existential question of survival amidst a landscape shaped by technology, regulations, geopolitics, and climate change. Amidst these multifaceted challenges, academic research emerges as a beacon of hope, offering innovative solutions to navigate the turbulent waters ahead. This paper delves into the pivotal role of academic research in advancing sustainability within the maritime sector, focusing on hull design, propulsion equipment, vibrations, and underwater noise.

Through a comprehensive review of literature and case studies, this study elucidates how cutting-edge research in hull optimization, propulsion system efficiency, vibration reduction techniques contributes to enhancing the environmental performance and operational efficiency of vessels. Furthermore, it examines the synergistic interplay between technological innovation, regulatory frameworks, geopolitical dynamics, and climate imperatives in shaping the future trajectory of global shipping.

By shedding light on the symbiotic relationship between academic research and the maritime industry, this paper underscores the transformative potential of collaborative endeavours in driving sustainable practices amidst the evolving global challenges. Ultimately, it posits that academic research serves as both a torchbearer of hope and a catalyst for change, offering actionable insights to steer the maritime industry towards a brighter and more sustainable future.

Keywords: Hydrogen; Methanol; Antifouling; Hydrodynamic; Hybrid system; Streamlined

Emerging Propulsion Equipment: Methanol

Green Methanol (CH_3OH) produced from renewable sources is an attractive marine fuel option due to its low carbon intensity. An engine using green methanol can even provide carbon-neutral propulsion. Methanol inclusion in the IMO's Interim Guidelines for Low Flash Point Fuels was passed in November 2020. It may be used onboard ships as fuel for internal combustion engines or as a fuel source for fuel cell operation.

MAN has developed the 'ME-LGI' concept for high-pressure injection of liquid low flashpoint fuels such as methanol. This involves a relatively low fuel supply pressure, and all high-pressure pumping is done within the injector. Fuel injection is accomplished by a booster fuel injection valve that raises the injection pressure to 550-600 bar. The first application of this concept was in methanol-burning Dual Fuel (DF) engines on several methanol carriers. As methanol is a liquid at ambient temperature, the existing liquid fuel infrastructure may also be leveraged for the supply of methanol with limited conversion. As a liquid fuel, only minor modifications are needed to existing systems/infrastructure used for conventional marine fuels. The modifications are mainly concerning the low flash point of methanol. Hence less funds will be required for the vessel owners to propel the ships using methanol by minor modifications in the

> *Keeping the zero carbon policy into consideration , MAN has developed world's first two-stroke dual-fuel engine named MAN B&W ME-LGIM which can run on both methanol as well as conventional fuels*

existing two stroke IC engine. Keeping the zero carbon policy into consideration , MAN has developed world's first two-stroke dual-fuel engine named MAN B&W ME-LGIM which can run on both methanol as well as conventional fuels. Specifically designed to meet the needs of the maritime industry, it is a versatile and scalable solution that is suited to a wide range of vessel types. Simple handling, storage, and bunkering of methanol, combined with relatively simple auxiliary systems and the potential to be carbon-neutral, makes it an attractive option for meeting decarbonization targets. The engine works with even better efficiency compared to our conventional fuel engines. Switching between methanol and fuel oil is seamless and thereby supports reliable and continuous operation of the engine.

Overlooking this transition towards green and environmentally sustainable shipping , the leading maritime trade giant MAERSK has placed and order of 19 vessels propelled by green methanol in pursuit of achieving the zero emission dream of the company. Following this , many other companies are also taking the same path.

Figure. 1 MAN B&W ME-LGIM

Large scale production of green methanol is a biggest challenge for which various countries as well as companies are heavily investing in infrastructure for the same. If the production capacity is increased , it will make this green fuel more cost effective . one other drawback that can raise concern is Methanol's specific energy of 19,700 kJ/kg is much lower than that of LNG and conventional liquid fuels. For the same energy content, methanol requires about 2.54 times more storage volume than conventional fuels which needs to be addressed.

Hydrogen

Hydrogen fuel cells operate by creating electricity through a chemical reaction. Each fuel cell consists of a negative electrode called an anode and a positive electrode called a cathode. The electricity is produced at these electrodes, facilitated by an electrolyte that carries electrically charged particles between them, along with a catalyst to accelerate the reactions. While hydrogen serves as the primary fuel, oxygen is also required for the fuel cell to function. It has minimal environmental impact, as the combination of hydrogen and oxygen produces water as a by-product, therefore entirely free of carbon emissions. Because fuel cells utilize an electro-chemical reaction rather than combustion, they can achieve higher efficiencies compared to traditional energy production methods. This efficiency can be further enhanced by combined heat and power generators, which utilize waste heat from the cell for heating or cooling applications.

While single fuel cells do not produce a large amount of electricity, they are combined into stacks to generate sufficient power for their intended use, whether it's for small digital devices or large power plants. Unlike batteries, fuel cells do not require recharging and can continuously generate electricity as long as the fuel source, in this case, hydrogen, is provided. With an anode, cathode, and an electrolyte membrane, fuel cells have no moving parts, making them both quiet in operation and

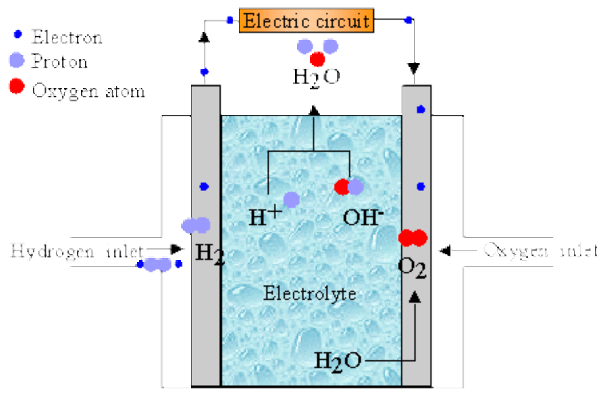

Figure. 1.2 Hydrogen fuel cell

> *Because fuel cells utilize an electro-chemical reaction rather than combustion, they can achieve higher efficiencies compared to traditional energy production methods*

highly reliable. Additionally, hydrogen can be directly burned in internal combustion engines aboard ships, similar to conventional fossil fuels such as diesel or gasoline.

Hydrogen can be produced through various methods such as steam methane reforming (SMR), electrolysis, and biomass gasification. Onboard ships, hydrogen gas is stored in high-pressure tanks or cryogenic tanks.

Hulls and Ship Structure

The ship's watertight enclosure is crucial for safeguarding the cargo, machinery, and accommodation spaces from weather, flooding, and structural damage. An advancement in ship hull materials is the adoption of fibre-reinforced composites like carbon fibre and fiberglass, renowned for being lighter and stronger than traditional steel.

CAD Software

Employing CAD software for ship hull design has tremendously impacted the shipbuilding industry. The 3D representation created using CAD tools allows for precise modelling of hull surfaces, essential for subsequent design and calculations such as hydrodynamics, stability, and tank definition. B-spline curves and surfaces serve as the basis for representing the ship hull's curves and surfaces within the CAD software, offering flexibility in achieving the intended hull shape.

Laser Scanning

When it comes to measuring ship hulls for hydrodynamic simulations, the preference for surface-based measurements arises due to the complexity and deformation of the original shape in some cases. Methods such as terrestrial laser scanning (TLS) and close-range photogrammetry are continuously evolving for comprehensive data acquisition, particularly capturing the entire vessel's body out of the water. For research analysis purposes, the use of scanners like Surphaser 400 and Faro Focus 3D 120S, along with Geomagic DesignX software for meshing the cleaned, co-registered, and resampled point clouds, can be instrumental. Additionally, modifications aimed at reducing the ship's resistance and consequently fuel consumption are worth considering.

Antifouling coating

The hull of the ship is coated with antifouling paint to prevent the growth of marine life such as algae, mussels, and barnacles. This type of paint typically contains copper and zinc, which are effective but have toxic effects on marine organisms. To address this issue, the US Office of Naval Research has been funding research into developing environmentally friendly alternatives for over 20 years. The goal is to create coatings that do not harm marine life but still prevent organisms from adhering to the ship's surface. One promising solution involves using a biocompatible polymer called PEG in fouling-release coatings. This polymer forms a slippery surface that prevents biofilms and proteins from sticking without harming marine life.

While this alternative shows potential, there is a need to overcome challenges in transitioning from traditional antifouling paints to this new coating. Additionally, it is important to find a solution that is both nontoxic and cost-effective to replace the current toxic substances in marine paints.

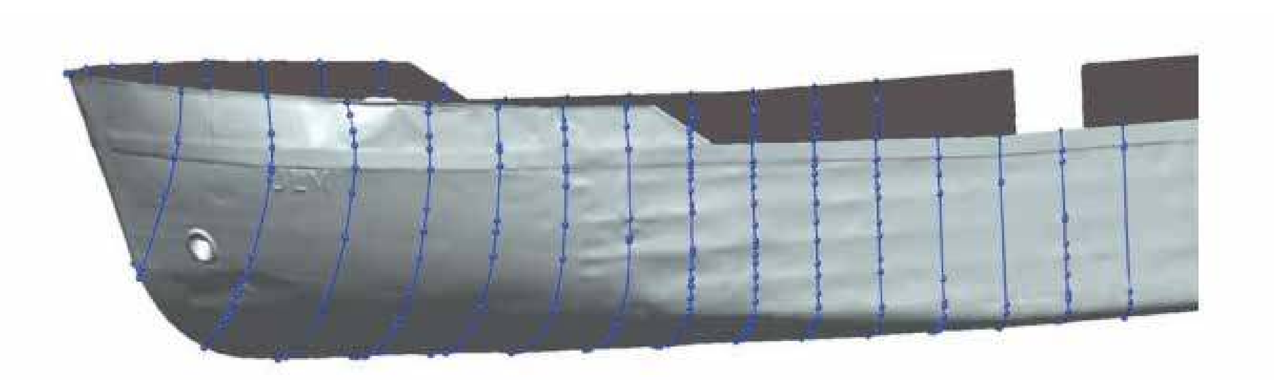

Figure. 1.4 Cross-sections taken at pre-defined locations

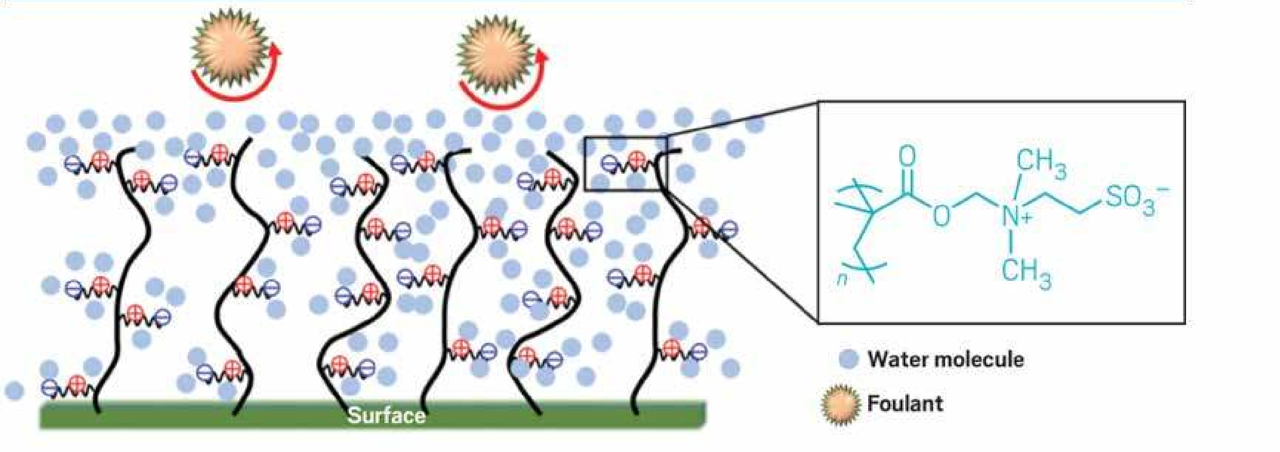

Figure. 1.3 Poly sulfobetaine methacrylate, a zwitterionic material

These materials use zwitterions, molecules with equal numbers of positively and negatively charged groups, attached to polymer chains in alternating patterns to build a strong, stable water layer that prevents organisms from adhering to a surface, thus inhibiting biological growth.

Fundamentally, zwitterionic materials represent a shift in paradigm for antifouling solutions.

Rather than killing organisms or using shear forces to push them off, zwitterionic coatings make ship hulls effectively invisible. After years of trial and error, the commercialization of these materials is in sight, Jiang says. The new materials' benefits go beyond blocking the necessary organisms. Hydrogels used in antifouling for ship hulls create a slippery surface that prevents marine organisms from adhering. They work by releasing water or other substances to form a barrier, reducing friction and fouling accumulation. This eco-friendly approach minimizes the need for toxic chemicals and improves ship efficiency by reducing drag, leading to lower fuel consumption and maintenance costs.

Vibration and Underwater noises

Mechanical disturbances and the transmission of sound waves through water cause vibrations and underwater sounds in the sea. These vibrations can originate from sources such as ships, marine machinery, and underwater construction activities, potentially impacting marine life and ecosystems.

To address these concerns, quiet ship design incorporates advanced hull shapes, propeller designs, and insulation materials to reduce vibration and underwater noise.

Quiet ship design

In advanced hull shapes, propeller designs, and insulation materials are being researched upon to minimize vibration and underwater noise. By optimizing structural integrity and propulsion systems, such designs reduce disturbances that could otherwise impact marine environments and wildlife, enhancing overall acoustic stealth and environmental sustainability.

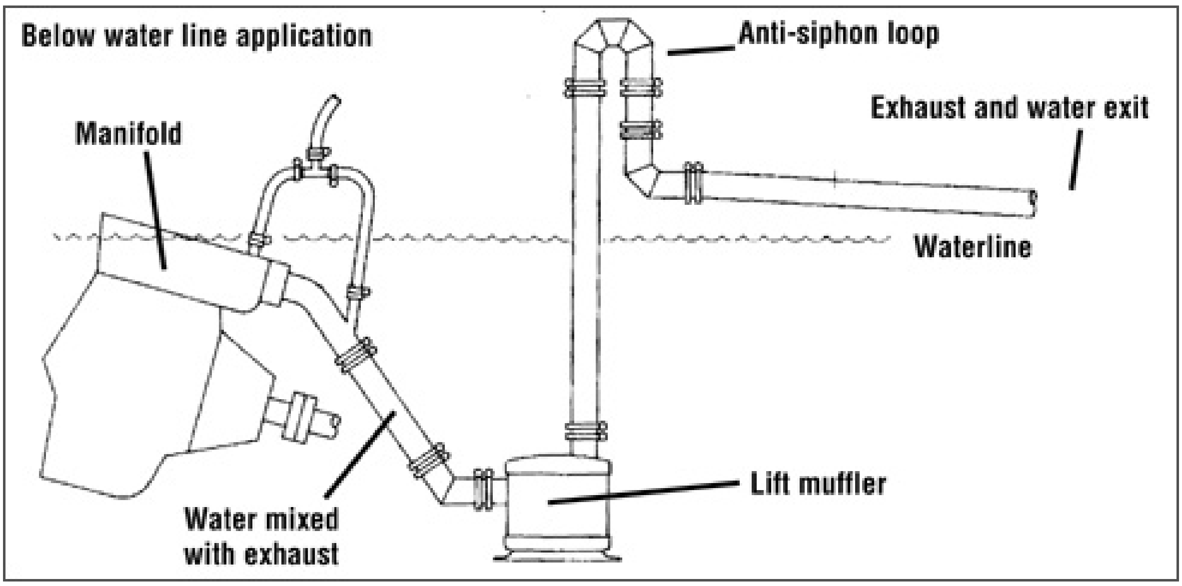

Figure. 1.5 Exhaust system

> *Active noise control systems reduce vibration and underwater noise by emitting precise anti-noise waves that cancel out undesirable noise frequencies generated by ship machinery*

Advanced propulsion systems

Such as electric and hybrid engines, reduce vibration and underwater noise by operating more smoothly and efficiently compared to traditional diesel engines. They produce fewer mechanical vibrations and eliminate noisy components like gearboxes, contributing to quieter and environmentally friendly marine operations

Hull shape optimization

This reduces vibration and underwater noise by minimizing hydrodynamic drag and turbulence. Streamlined hulls experience smoother water flow, reducing the forces that cause vibrations. This design also lowers cavitation risk around propellers, which decreases noise generated by collapsing bubbles. Overall, it enhances acoustic stealth and environmental sustainability in marine environments.

Active noise control systems reduce vibration and underwater noise by emitting precise anti-noise waves that cancel out undesirable noise frequencies generated by ship machinery. By actively interfering with and neutralizing noise waves, these systems significantly lower overall noise levels in marine environments, enhancing acoustic comfort and environmental sustainability..

Underwater exhaust systems direct engine exhaust gases away from the ship's hull, reducing underwater noise caused by turbulent exhaust discharge. By minimizing disturbance to water flow around the hull and propeller, these systems contribute to quieter marine environments and mitigate acoustic pollution, benefiting marine life.

Vibration control mounts are used to reduce vibration and underwater noise by isolating machinery and equipment from the ship's structure. These mounts are typically made of materials like rubber or elastomers and are designed to absorb and dampen vibrations generated by engines, propulsion systems, and other mechanical components.

Hence it is important for each and every generation to enhance and power academic research which would be the strong foundation of a more efficient and environmentally sustainable future of the shipping and related industries and hence benefit the whole mother earth.

[This Paper was presented in the WMTC 2024, 4-6 Dec, Chennai, India]

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Article Parametric Generation of Small Ship Hulls with CAD Software Francisco Pérez-Arribas * Universidad Politécnica de Madrid (UPM), 28040 Madrid, Spain

Seeking Nontoxic Coatings to Keep Ship Hulls Clean | ACS Central Science

Laser Scanning Ship Hulls to Support Hydrodynamic Simulations | Periodica Polytechnica Civil Engineering (bme.hu)

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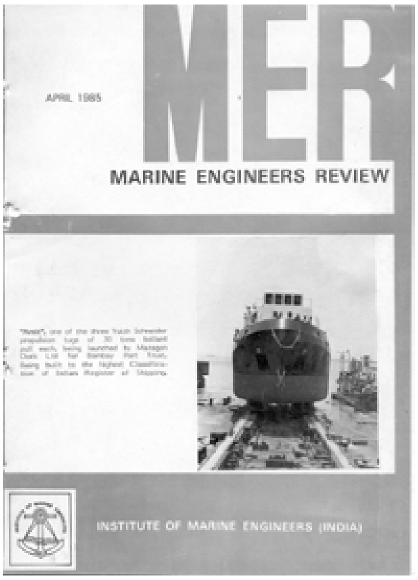
Email: atharvagbhoite@gmail.com

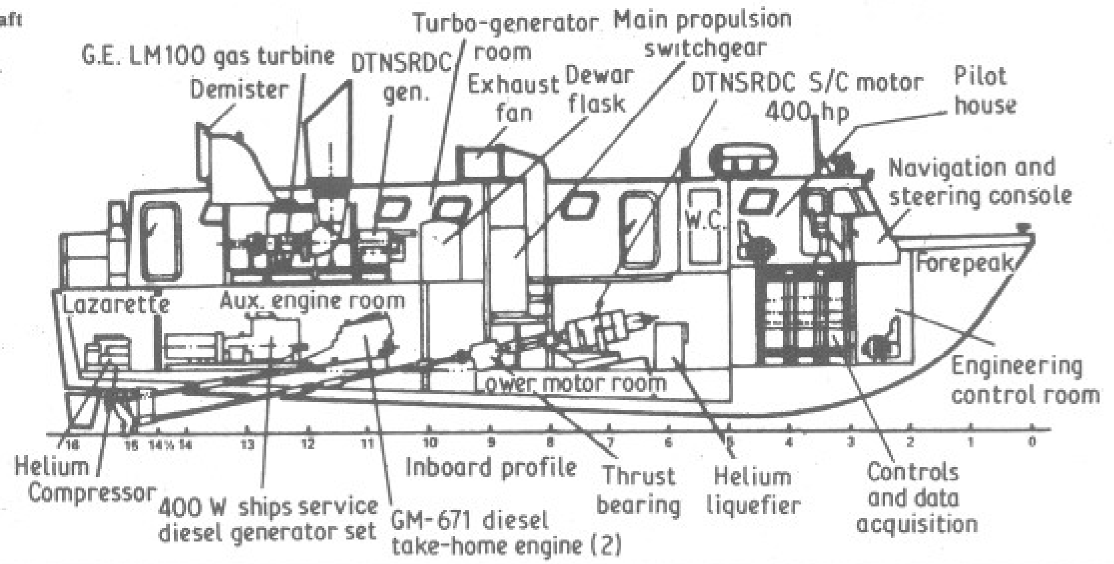
Going Astern into MER Archives…



The Editorial starts with a mention of the Bhopal Gas tragedy and a bitter note that such accidents can happen in the countries of rich people whose minds have been disturbed by the loss of lives etc. Further, there is a suggestion that to avoid such disasters, it is necessary to estimate the possibility of such events occurring. Fault Tree Analysis and Quantitative Risk Analyses also get a mention with a few examples of LNG trade.

Moving on, the first article is on Electrical propulsion followed by another article on super conducting DC drives for the same purpose.

Fig 4: Testcraft equipment arrangement.



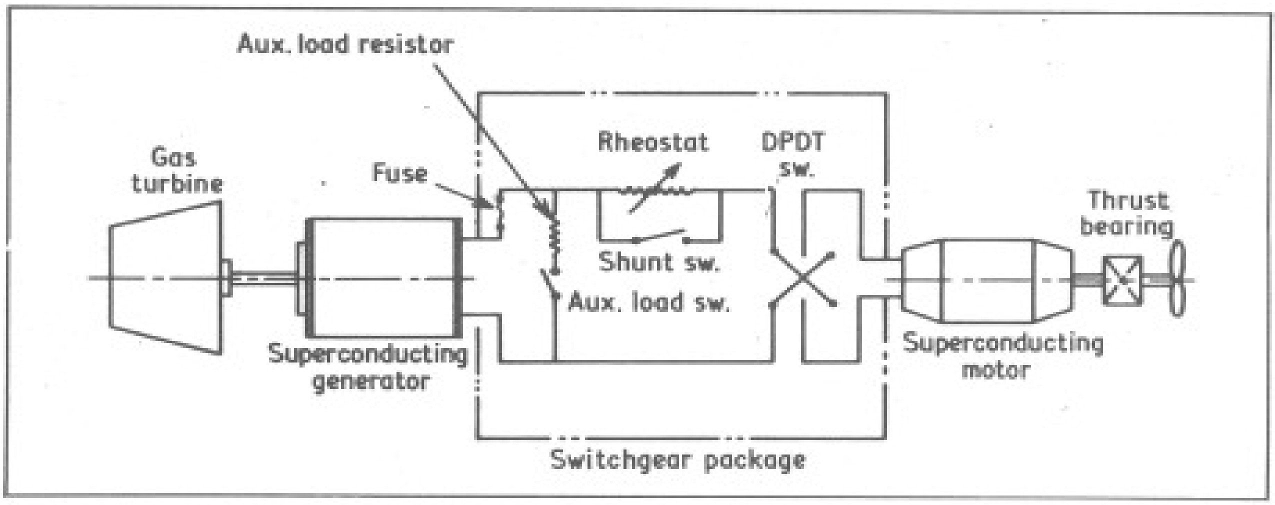


Fig 3: 400 hp electric propulsion system.

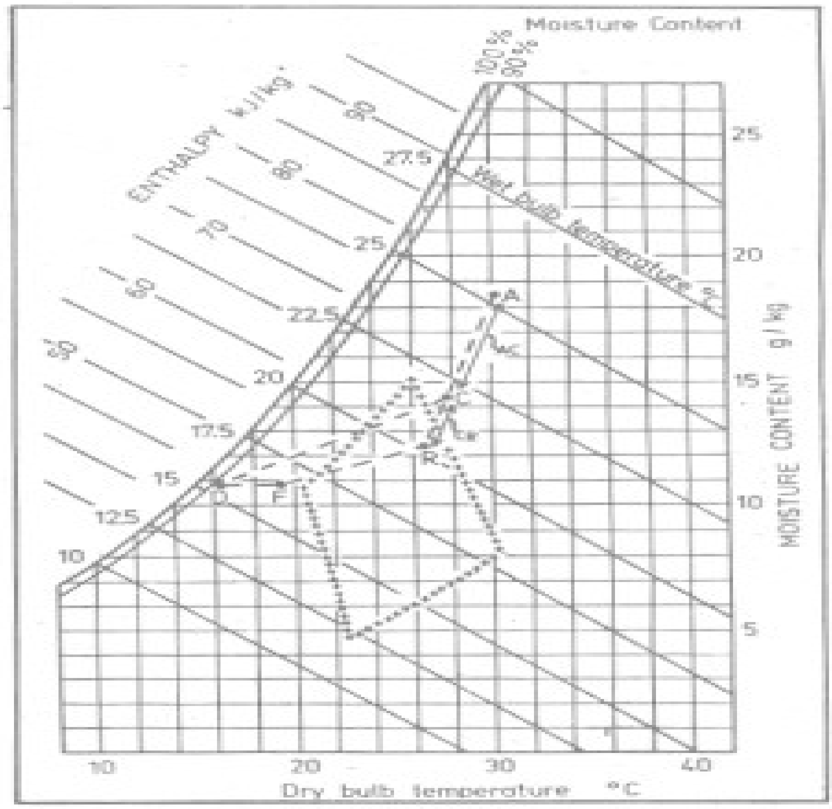


Fig 1: Psychometric chart relating variables.

This is followed by a discussion on CAD for marine air conditioning. This will be of interest to practicing marine engineers.

Another interesting article is on noise reduction in accommodation areas employing a dampening steel plate (developed by NKK). Tests on about two vessels are also discussed. Marine engineers with experience on such applications may share their experience.

There are other articles on: Mirrlees engine, effects of cargoes shifting on the ship, reduction in operating costs.

There is one Transaction on 'Evaluation and Prevention of Electrostatic Hazards associated with Oil Tanker Operations (read on April 11, 1983) and another paper on 'Liability Avoidance in Ship Design and Construction'.

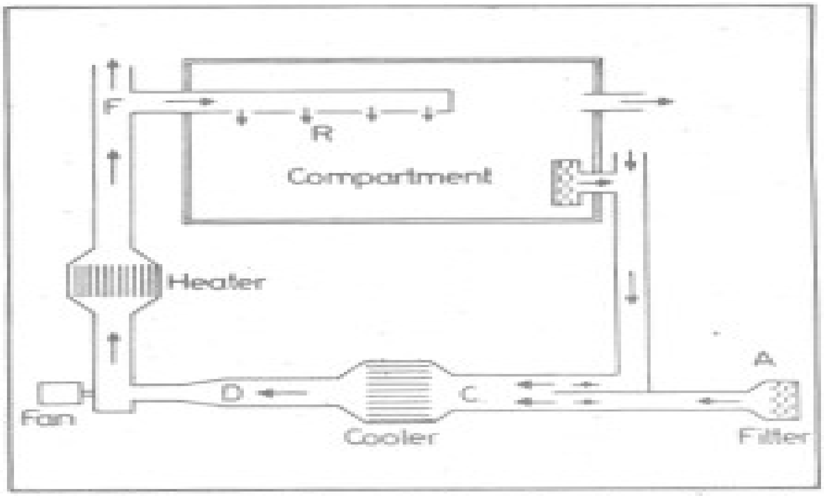
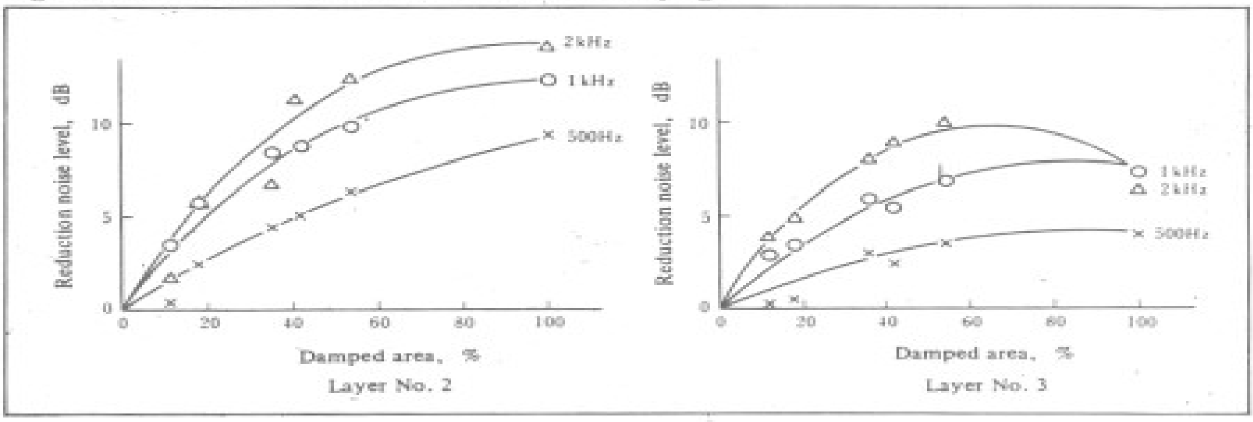
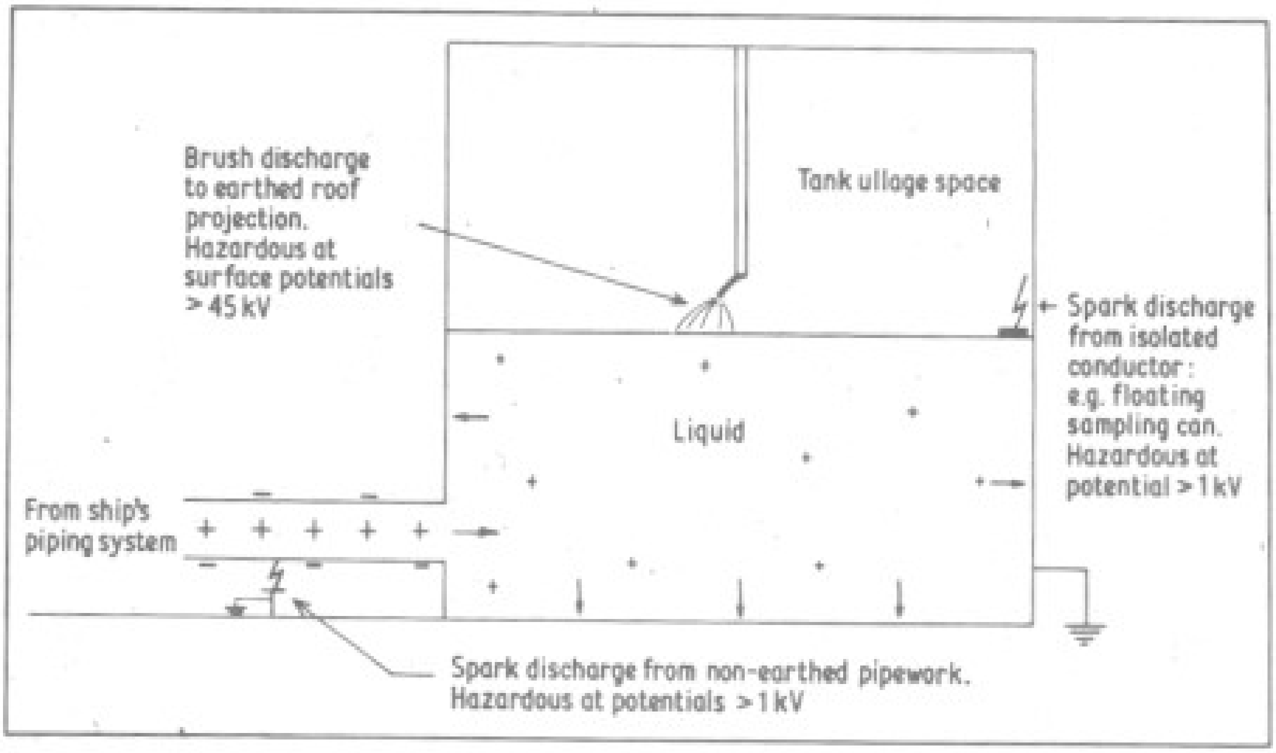
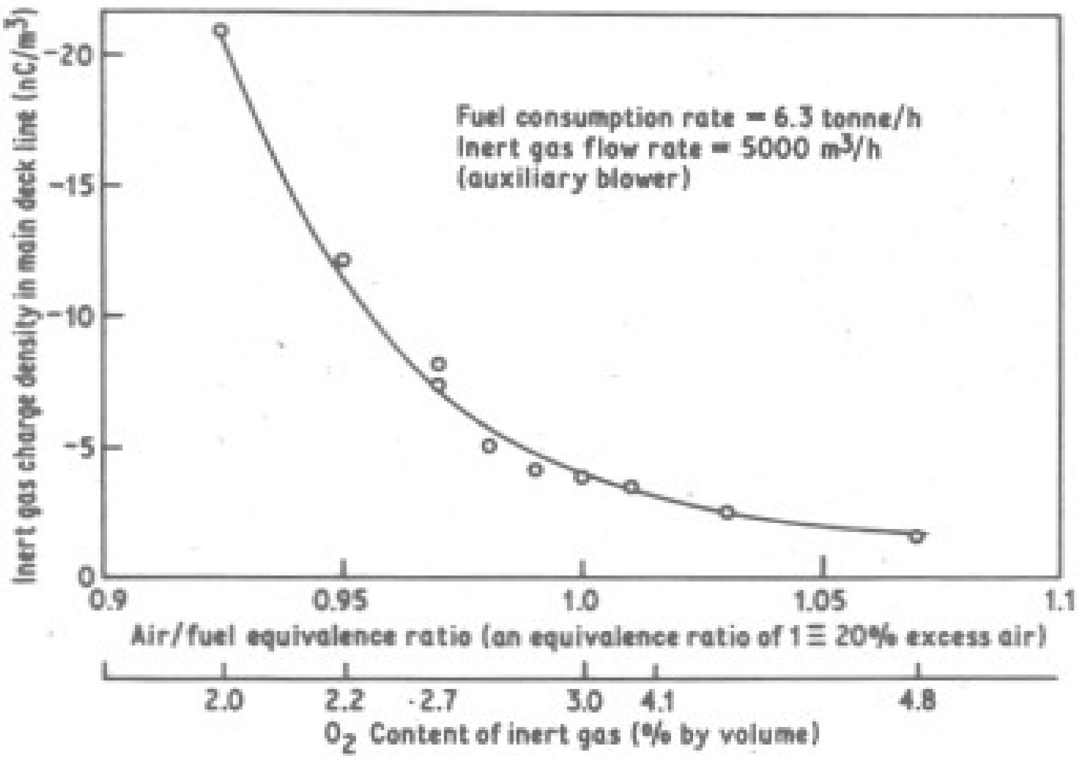


Fig 2: Schematic layout of a simple marine air-conditioning system.

Fig 2: Measured noise reduction with increased damping.







Fuel consumption rate = 6.3 tonne/h
Inert gas flow rate = 5000 m³/h (auxiliary blower)

There is a news release on Wärtsilä and MAN-B&W signing an Licence Agreement.

POSTBAG has a letter on numbering of engine units (free end or power take off end is the question). There are other letters on LNG tanks and on fuel blending.

POSTBAG

Wrong number?

Sir,
I refer to the letter of Mr A K Asamoah (February Postbag) on the subject of designation of engine cylinders.

For many years it has been the practice of Lloyd's Register of Shipping to number cylinder units from forward and indeed every Master List of Surveyable Items carries the statement: 'Machinery—all engine components numbered from forward'.

In 1972 an International Standard—ISO 1205—was published which called for cylinders to be numbered from the power output end of the engine and all surveyors are aware that this has caused a need for care in reporting because of adoption of ISO 1205 by *some* engine builders.

In 1978 the Society sought the views of engine builders throughout the world and, when it became clear that the industry was sharply divided, the decision was made to maintain the policy of numbering from forward. In 1982 a further worldwide review was carried out and the results revealed that there was still a great division of opinion, and indeed intent, in this matter.

One leading engine builder will continue to number from the free end all engines of established designs and will apply the ISO 1205 system only to the latest and future designs. Another prominent builder has resisted the proposed change to ISO 1205 and has decided that they will not adopt it until they are shown to be the last manufacturer not to conform.

The Japanese builders are divided almost equally in favour of the two methods and licensees are almost bound to follow the policies of their licensors because of their dependance upon designers for drawings.

In the USA the adoption of ISO 1205 is deplored as an unnecessary and costly exercise which will be ignored.

From the foregoing review it is evident that, should the Society alter its numbering system, the problem would be solved for some ships and transferred to others.

A simple, practical means of overcoming the difficulty will be for owners to place in the offices of chief engineers, diagrams similar to those attached hereto, whereby surveyors and chief engineers can mutually agree on the numbers to be recorded and reported.

R F Munro
Senior Principal Surveyor
Lloyd's Register of Shipping
London.

Sir,
With reference to the letter by Mr A K Asamoah, it is well known that engine-builders disagree in their methods of numbering parts. The correct bearing would have been that numbered 'seven' in the maker's instruction book.

Mr Asamoah asks for a standard. Surely such a standard would most sensibly be the stamping of each bearing number on the bed adjacent to the bearing: quite apart from the numbers of the bearings to each side.

Whilst writing, may I be permitted to ask whether there are any Esperantists among fellow members?

Richard J Davies
THV *Mermaid*.

LNG tanks compared

Sir,
With reference to previous correspondence and to Mr T Watanabe's letters (Postbag Nov 84) we have the following comment.

There is a distinct difference between the first NKK statement: "These membrane types (Mk I and Mk III) are said to have a 20-year proven superiority to spherical tank-type LNG carriers in safety performance," and the second one: "The Technigaz Mk I is said to have a 20-year history of safe performance . . ."! Additionally, it is a fact that TGZ Mk III has never been in regular service.

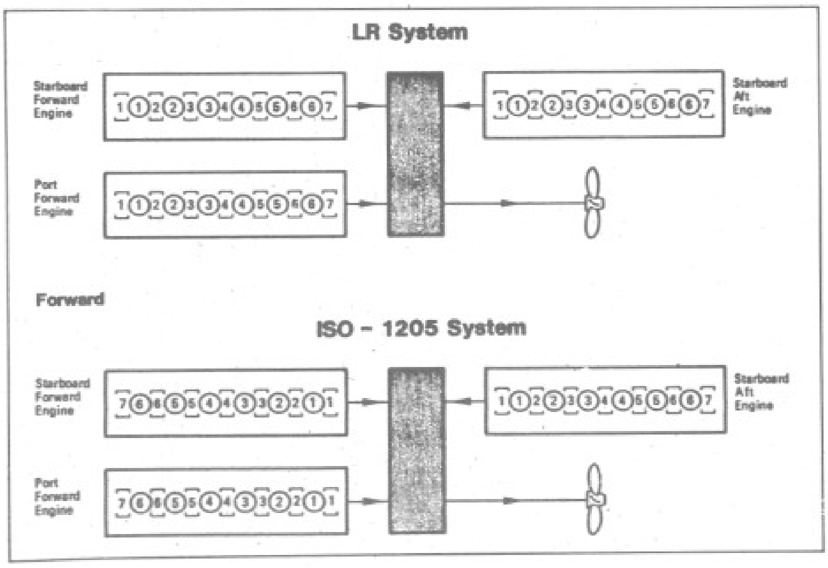
We also find it misleading for NKK to bring the Sener system into the discussion because this system has never been used in regular LNG service. Maybe one reason was that the Sener system differs considerably from the Moss type.

We do not think that minor differences in principal dimensions will have any decisive effect on the choice of tank system. This should be demonstrated by the fact that the Moss system was chosen for the seven latest LNG ships ordered, built in Japan for Japanese owners.

Finally, we are convinced that nobody familiar with LNG ship building would rely on NKK's claim that the construction of the spherical tank, including insulation, requires twice as much manhours as the membrane tank. The opposite seems more reasonable.

Halfdan H Iversen
Asst Director
Moss Rosenberg Verft

Two ways of numbering cylinders—the LRS method and the ISO standard



Unifuel ship

Sir,
Regarding your Opinion on blending and the unifuel ship in the January MER, we feel it necessary to clarify the range of views given at the discussion.

The majority of marine bunkers supplied today are blended. The increasing use of blenders on ships over the past decade has become necessary due to the deteriorating quality of the heavy fuel supplied in many parts of the world. If one can blend effectively on board, utilising similar facilities to those used by oil suppliers, the quality of the fuel to the engine will be no worse than that purchased at premium price. The fact that the blending ratio can be controlled to vary viscosity is an added bonus.

It is an accepted engine room phenomenon that the conditions of combustion at specific times during a voyage change with the same fuel (seawater temperature, ambient temperature, load conditions, etc). Perhaps the most important point is varying load requirements, and an important part at the seminar emphasised the feature of the Sea Star blender as being load sensitive.

In your final summing up we were pleased to note you had referred to the engine-builders not yet having persuaded all operators that diesels run satisfactorily at low loads. All engine builders would probably agree that combustion is not as good at low loads and most engine-builders would agree that improved fuel quality at low load is an advantage. This is a specific feature of the blender which operators find attractive.

A S Coates
Hamworthy Engineering
Dorset.

We invite observations, discussion threads from readers, taking cues from these sepia-soaked MER pages. – Hon.Ed.

IME (I) GOVERNING COUNCIL, BRANCH, AND CHAPTER COMMITTEE ELECTIONS 2025-27

As the elections for The Institute of Marine Engineers (India) approach, we wish to notify all Corporate Members of the following procedures:

SCHEDULE

Soft Copy of Nomination Papers:

- The entire election process will be communicated exclusively through electronic media.
- Nomination forms will be sent via mass email and can also be downloaded from the IME(I) website. Completed forms must be returned to the Election Officer.
- Nomination papers for Council elections will be emailed by **15th May 2025** to the registered email ID.
- The Institute's office must receive the completed nomination papers by **15th June** 2025.
- The last date for withdrawing nominations is **30th June 2025**.
- The Election Committee will complete the scrutiny of nomination papers by **5th July 2025**.
- After scrutiny, the Election Officer will publish the CVs of eligible candidates on the IME(I) website.

E-VOTING

As a Corporate Member (on the Roll as of **15th May 2025**), you can cast your vote in the upcoming IME(I) elections using the **e-Voting** system exclusively.

- Two voting options will be available:
    - o **Head Office (HO) Elections**
    - o **Branch Level Elections** (if applicable)
- Overseas Members will have the option to vote **only for the HO level elections**.
- If your email address has changed, you must update it by emailing **electionofficer@imare.in** no later than **15th June 2025**.
- Members will receive the e-Voting link **only** at their registered email addresses as per IME(I) records on **1st June 2025**.
- To update your email ID or contact details, write to **membership@imare.in** by **10th May 2025**.
- E-Voting will commence on **15th July 2025** and remain open until **1700 hrs on 31st August 2025**.

ELIGIBILITY TO STAND FOR ELECTION

- All office bearers of the **Council and Council Members** must be **Fellow Members** from branches or chapters only.
- Office bearers and Council Members must have been Corporate Members for at least four years at the time of filing their nomination and must have served at least one full term on the executive committee of a local branch or chapter before being eligible to stand for election from that branch.

USE OF WORKPLACE / OFFICIAL EMAIL IDS

- In the past, mass emails have been blocked by certain organization domains, flagged as spam, or led to the blacklisting of the IME(I) domain. To avoid this, we **strongly recommend using personal email IDs only**.
- Using your personal email ensures you receive all important election-related communications.

For any queries, please contact: **Election Officer**
electionofficer@imare.in

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RNI No. MAHENG/2006/19917
W.P.P. Licence No.:
MR/Tech/WPP-336/ South/2018-20

IME(I) House, Nerul, Navi Mumbai