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Vessel Data Visions for Decision Making

The Institute of Marine Engineers (India)

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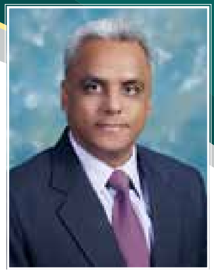
EDITORIAL



He that can have patience can have what he will.
- Benjamin Franklin

Maritime news continue to flood the sectoral discussion decks and forums.

The 5 Bills continue to occupy conversations and there are just reasons that are projected.

In a democracy, issues need to be debated and laundered well so that decisions appear as deliberated outcomes rather than decrees of disposals in haste. On these lines is the first lament that the bills were not discussed as much. However, the bills were supposed to have been in the public domain for comments for a considerable period of time (some fact checking will help).

The next pointed punch is that the approaches erode the federal character and tend to force a central decision than allowing freedom for the States to do the maritime acts. A comparison on the development of major and other than major ports, efforts on the inland waterways etc., might show the lowered scale-plate and what could be advantageous: whether a centralised channelizing would help or an independent states' action would bring faster progress.

Other areas of concern include: dispute resolution issues, vessel ownership and registration, coastal operators' regulations etc. A fact which stands unnoticed is that rule-writing on all these Bills has to follow wherein many of these issues will see better light and reason.

While INMEX (International Maritime Exhibition and Forum) brought together many speaking heads on all these maritime matters, maritime will continue to occupy the discourses and answers will emerge. A waiting will help. We may say that the lights and the lighthouse are being sighted, but some patience will get us to the shores, ports and the berths in good time.

In this issue

We start with a WMTC paper. Dr. Bojan Vučinić and Dr. Dean Vučinić discuss a proposition on 'vessel visions,' wherein ship data is processed for vessel operators etc. This process of building vessel data through a Domain Specific Language (DSL) is aimed at helping optimise the life cycle costs and also help in better data governance. Starting with a 'Functional Decomposition and defining the ship type, the Authors go through the steps of design, manufacturing (building) and putting the vessel into operation (AI, Large Models etc., are to be employed here). Adding another component, 'end-of-life management', completes the stages. Then comes the various parties the vessel will encounter in her life (Classification Society, IMO et al.). Integrating the requirements of these parties and the operational data, a digital twin can be envisaged. The article in a way educates the approaches to understanding a Digital Twin.

The next article by Praveen Bakhsi focusses on Marine Spatial Planning (MSP). The Author explains MSP, the rationale for this planning and also the initiatives taken up by India. The take away is the information on SAHAV (Spatial Analysis for Harmonized Allocation of Marine Space), India's first open-source web-based platform. This is an easy read to keep updated.

We follow with another educative article on Polar Shipping and challenges in designing systems on board vessels plying in the ice conditions. Dr. Vedachalam et al., explain the additional factors to be considered for complying with ice-class rules. Ship's structural capabilities, ice environment and operational modes, and importantly the safety aspects are discussed. This is an easy read, though a bot lengthy.

Under Technical Notes, Sanjay Relan explains the IMO's strategies on dual fuel vessels. Also, Dr. Shantanu Paul enlightens a few legal aspects assuming a hypothetical case of a tanker explosion and foundering. The MER Archives from October 1985 carries four absorbing Transactions on auxiliary power generation (shaft generators, turbo alternators etc.). This should certainly interest the marine engineers of yesteryears and now.

The India Maritime Week (IMW, slotted for last week of October 2025) is expected to impress on the commitment towards a self-reliant (atmanirbhar) maritime nation. With best wishes for the oncoming IMW, here is the October issue for your reading pleasure.

Dr Rajoo Balaji
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Vessel Data Visions: Data Management Considerations for Optimum Life Cycle Costs

Bojan Vučinić
Dean Vučinić

Abstract

This paper introduces the Ship Digital Twin, employing a knowledge graph database and deep learning to advance the operational and maintenance efficiencies of maritime vessels. At the core of this initiative are "vessel visions," customised views of ship data tailored for specific maritime stakeholders like class societies, flag states, ship operators, port authorities and others. Each vision is crafted through a domain-specific language (DSL), facilitating stakeholder-specific interfaces that access and interpret the digital twin's data effectively. The knowledge graph database underpins these visions by structurally encapsulating ship data, enabling complex queries and dynamic data relationships that support precise decision-making processes. This system not only refines life cycle costs but also enhances safety and environmental sustainability through proactive management. This integration facilitates a holistic view of ship operations, supporting the optimisation of life cycle costs and improving safety and environmental sustainability. Through the digital twin, stakeholders including ship owners, operators, and regulatory bodies gain unprecedented insights, driving efficiencies and reinforcing industry standards. The paper details the development of these specialised visions, the application of deep learning for robust data analysis, and the transformative impact on maritime industry standards.

Keywords: ship; data governance; digital twin; maintenance management; life cycle costs

Introduction

The maritime industry is experiencing a transformative shift with the advent of Digital Twin technology, which creates virtual replicas of ships for real-time monitoring and optimisation. This paper introduces the Ship Digital Twin framework, utilising a knowledge graph database to enhance operational and maintenance efficiencies and improve data governance.

Central to this framework are "vessel visions," tailored views of ship data for specific actors such as class societies, flag states, ship operators, and port authorities. These customised interfaces, created using a domain-specific language (DSL), allow actors to effectively access and interpret the Digital Twin's data.

> *These customised interfaces, created using a domain-specific language (DSL), allow actors to effectively access and interpret the Digital Twin's data*

The knowledge graph database structures ship data to support complex queries and dynamic relationships, enabling precise decision-making. By organising data in a highly interconnected and accessible manner, the knowledge graph enhances data governance. The benefit of using a Knowledge Graph database is that both structured, semi-structured and unstructured data made accessible and can contribute to the decision-making process.

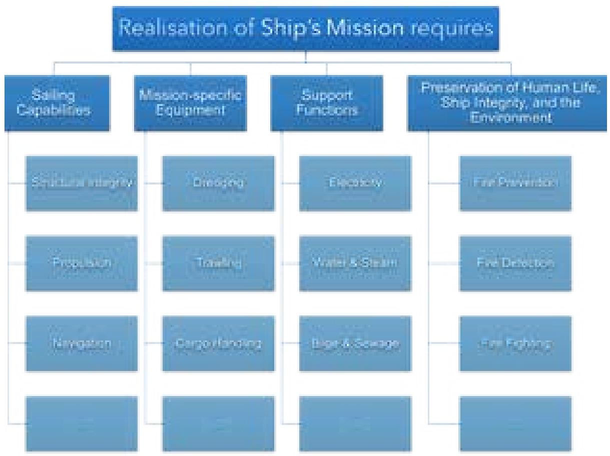
The Ship Digital Twin not only optimises life cycle costs but also enhances safety and environmental sustainability. This paper details the technical architecture, development of data mappings (which in turn specify domain-specific languages) and the implementation of the knowledge graph database.

The Ship (internal) Vision

Let's start our data governance journey by the knowledge of the ship as the central piece (node) of the Ship Digital Twin Framework.

The ship represents a complex technical installation. We'll have to see the ship as a collection of processes (functions) needed to realise the ship's mission (her purpose).

The Ship's Functional Decomposition will provide us with substantially structured data regarding ship's systems and their interdependencies (relationships). This fairly static information will form the skeleton of Ship's Digital Twin. Every item will belong to one of the systems as shown below [1].

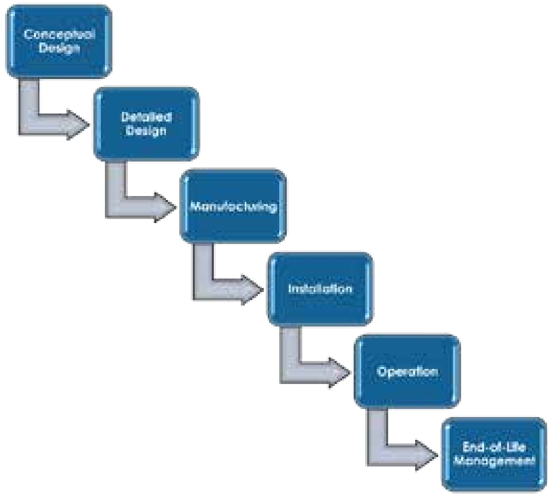


The functional decomposition is highly dependent of the ship type. These structured data should be enriched with scientific studies going from Numerical (e.g., FEM models) hull models, physical 3D models (e.g., towing tank models) to process models Reliability Block Diagrams (RBD) as proposed by [7], all to be kept in the Digital Twin Framework

The Ship (Temporal) Vision Ship's Life Cycle Phases

The life cycle of a ship encompasses several critical phases [2], each with specific activities and objectives aimed at ensuring the vessel's optimal performance, safety and compliance throughout her operational life. Last but not list the overall Lifecycle Costs (LCC) [3] are key to our optimisation and a primary factor in our decision making.

We use the life cycle to show the dynamic, transformative, time-based nature of the Ship Digital Twin. A typical life cycle is shown next:



The following sections outline these in terms of data visions:

Conceptual Design

Often this initial phase commences with research and exploration. We investigate new materials, propulsion systems and technologies applicable to shipbuilding and we conduct studies on hydrodynamics, fuel efficiency and environmental impact. The data in this phase are very general and broad in nature and as such very unstructured.

Once the explorative phase is sufficiently rounded, as this process continues, the initial Concept of the Ship is developed and evaluated, defining the vessel's purpose (e.g., cargo, passenger, research), size, capacity and general layout.

Detailed Design

Enter Detailed Design developing Engineering Plans and specifications. Many design decisions have been taken and the actual Digital Twin is starting to take shape and a vast amount of data is generated as: detailed engineering drawings, 3D models and prototypes. Although highly structured these data was historically not perceived as structured as being on paper. Fortunately, today with progresses in knowledge management, this is not the case anymore and the semantic data is stored natively via Model Based Definition tools like MBDVidia [8].

Manufacturing

Once the design is rounded, at least for the hull we can begin ship construction in a shipyard, including sourcing materials, fabricating parts and assembling the vessel. Today, with NC machines and highly automated manufacturing processes the data is exchanged flawlessly among machines. At this point, the design data are transposed into a physical product – the ship. Rigorous quality control is implemented throughout the process.

Installation

Once the ship is launched, outfitting her with all the designed equipment and systems is finalised. Sea Trials are usually the final quality control checkpoint prior to delivering the ship to the Ship Owner. In order to ensure it is ready for operation, this phase will include final adjustments, crew training and handover procedures. This is the final validation that the envisioned design was followed and its realisation the physical product is conform.

Operation

The Ship is put into active service and she performs its designated functions (e.g., transporting goods, carrying passengers).

This phase is usually the longest and represents the Useful Life of the Ship. It is also the source of a vast amount of data, which are highly unstructured (textual reports, photo snapshots, sensor readings etc.). This is also the phase that can benefit the most of AI in general and deep learning in particular, to guide our decision making with tools based on LLM's as proposed by Neo4j [12] and/or Cambridge Semantics [13];

End-of-Life Management

End-of-Life Management includes usually decommissioning, however we can envision Life Extension and other sustainability options. We can explore ways to extend the ship's life through refurbishing, retrofitting with new technologies, or repurposing for different uses. For example, a VLCC can be converted to an FPSO. Of course in terms of data this will give birth to a new digital twin for the FPSO, for which the VLCC historical data shouldn't be of much use, however it will be of vital value for future VLCC designs.

In summary, we listed the different phases of a single ship. However, the real power lies in the recursive use of previous life-cycles in the data analysis of future ones:

In this way the repetitive nature of one phase's data vision becomes available for the data analysis, by creating a Domain Specific Language (DSL) i.e. an ontology that will be stored in a Knowledge Graph.

"In addition to the temporal component of ship data captured by the ship's life-cycle phases, the Ship Digital Twin framework must accommodate interactions with various actors, each with specific data requirements essential for their roles"

The Ship's Actors and their Data Visions

In addition to the temporal component of ship data captured by the ship's life-cycle phases, the Ship Digital Twin framework must accommodate interactions with various actors, each with specific data requirements essential for their roles. These requirements vary in their level of structure, from highly structured scientific models and studies to more unstructured formats like textual inspection reports.

The following sections detail these actors and their data needs:

Environment

Environmental actors focus on the impact of the ship's operations on the marine and atmospheric environment, including emissions, waste management and ecological footprint.

Data Requirements:

- Structured: Emissions data (CO_2, NO_x, SO_x), fuel consumption.
- Semi-Structured: Waste generation and disposal methods, ballast water management.
- Unstructured: Impact on marine biodiversity.

Society

Societal actors are concerned with the broader impact of the ship's operations on communities and economies, including employment, safety and economic contributions.

Data Requirements:

- Structured: Employment data (number of jobs created), economic impact (contribution to local economies).
- Semi-Structured: Safety records and incident reports.
- Unstructured: Community engagement and development activities.

International Maritime Organization (IMO)

The IMO regulates shipping, focusing on safety, environmental concerns, legal matters, technical cooperation, maritime security and efficiency.

Data Requirements:

- Structured: Compliance with international regulations and conventions (MARPOL, SOLAS, etc.), emission control data.
- Semi-Structured: Safety management systems, port state control inspections.
- Unstructured: Incident and accident reports.

Port State

Port state authorities ensure foreign ships docking at their ports comply with international and local regulations through inspections and enforcement.

Data Requirements:

- Structured: Compliance with port regulations, arrival and departure schedules.
- Semi-Structured: Ship inspection records, cargo documentation.
- Unstructured: Security measures and protocols.

Flag State

The flag state is the country under whose laws the ship is registered. It ensures the ship adheres to international and national regulations.

Data Requirements:

- Structured: Ship registration details, compliance with national and international regulations.
- Semi-Structured: Crew certification and training records, maintenance and inspection records.
- Unstructured: Safety and security compliance.

Classification Society

Overview: Classification societies establish and maintain technical standards for the construction and operation of ships. They conduct surveys and issue compliance certificates.

Data Requirements:

- Structured: Structural integrity and stability data, safety equipment and procedures.
- Semi-Structured: Machinery and electrical systems, survey and inspection reports.
- Unstructured: Certification status and history.

Ship Builder

Shipbuilders are responsible for designing and constructing ships, ensuring vessels meet required standards and specifications.

Data Requirements:

- Structured: Design specifications and blueprints, material and component specifications.
- Semi-Structured: Construction progress and milestones, quality assurance and testing data.
- Unstructured: Compliance with classification society standards.

> ***The Ship Digital Twin framework leverages a knowledge graph to organise and manage data, with the storage method depending on the level of data structure***

Ship Broker

Ship brokers facilitate the buying, selling and chartering of ships, acting as intermediaries between ship owners and charterers or buyers.

Data Requirements:

- Structured: Ship specifications and capabilities, market conditions and trends.
- Semi-Structured: Charter party agreements, sale and purchase contracts.
- Unstructured: Operational performance data.

Ship Owner

Ship owners manage the financial, operational and regulatory aspects of the vessel.

Data Requirements:

- Structured: Financial performance data, operational efficiency and cost data.
- Semi-Structured: Compliance with regulations, maintenance and repair records.
- Unstructured: Crew management and performance data.

Ship Operator

Ship operators handle the day-to-day operations of the vessel, ensuring efficient and compliant functioning.

Data Requirements:

- Structured: Voyage planning and execution data, fuel consumption and efficiency.
- Semi-Structured: Cargo handling and logistics, real-time operational data (speed, position, weather conditions).
- Unstructured: Crew management and welfare.

The Ship Digital Twin framework leverages a knowledge graph to organise and manage data, with the storage method depending on the level of data structure. Structured data, such as emissions statistics or compliance records, can be directly transposed into nodes and relationships within the knowledge graph. Semi-structured data, including maintenance records and inspection reports, can be mapped to the graph with some preprocessing to standardise formats and ensure compatibility. In contrast, unstructured data, such as textual descriptions in inspection reports or community engagement activities, will be stored in a vector store model using embeddings. This approach enables advanced processing and analysis using Large Language Models (LLMs), which can extract insights and support decision-making processes.

Vessel Position & Status

Two key data elements (or nodes in the underlying Knowledge Graph) in the Digital Twin Framework are:

- **Ship Position**, attributes: Latitude, Longitude, Timestamp, Speed Over Ground (SOG), Course Over Ground (COG), etc.
- **Ship Status**, attributes: Status Type, Timestamp, Environmental Conditions, etc.

Ship Position (Based on AIS)

The ship's position is a crucial data element in the digital twin framework, primarily sourced from Automatic Identification Systems (AIS). Some popular providers of AIS services are:

- MarineTraffic [9],
- VesselFinder [10],
- Spire Global [11],

The Digital Twin framework will be connected to these data streams.

Ship Status (As per IMO)

The ship's status, as defined by the International Maritime Organization (IMO), provides a clear description of the vessel's operational condition and lifecycle stage. The usual Statuses are: Under Construction, In Service - At Sea, In Service – Port, In Service - At Anchor, Casualty, Repair, Laid up, Broken up, Total Loss. This can further be refined, if needed.

The objective of the Ship's Digital Twin Framework is to create a data store for the physical ship, capturing real-time data from various sources to provide a comprehensive view of its current state and environment

Absorbing External Data in the Ship Digital Twin Framework

The objective of the Ship's Digital Twin Framework is to create a data store for the physical ship, capturing real-time data from various sources to provide a comprehensive view of its current state and environment. In addition to the presented "Ship - Actor – Lifecycle phase" triad, the framework will record other external data streams as shown below:

A non-exhaustive list of external data sources that will enrich the Ship digital twin:

Port

Information on the port, including the number of mooring points, facilities available and loading/unloading equipment.

Shipyard

Data from the shipyard covering maintenance schedules, repair history and availability of dry docks.

Sea State

Real-time data on wave height, wave period and sea surface temperature, providing a comprehensive view of current sea conditions.

Weather

Integration of weather data streams [11], including temperature, pressure, wind speed [4] and direction.

Crew

Detailed information about the crew, including individual skills, experience and certifications.

Other

The Digital Twin Framework is designed to accommodate additional data sources as needed. **These could include cargo information, fuel consumption data [5], and other metrics.**

Data Ingestion and Integration

The digital twin will utilise a data ingestion platform capable of handling multiple data streams simultaneously. This platform integrates data from IoT sensors, external databases, and manual inputs.

IoT Sensors and Devices

Sensors placed on the ship, at ports, and in shipyards continuously collect data on various parameters such as structural integrity, equipment status, and environmental conditions.

APIs and External Data Sources

Weather data, sea state information, and other external data are ingested through APIs from trusted sources like meteorological services and marine agencies.

Data Processing and Storage

The ingested data is processed in real-time to ensure accuracy and relevance. A robust storage solution: the Neo4j knowledge graph [12] is implemented to store historical data for analysis and trend identification. It was selected in particular because it can store unstructured text (vector database), natively.

Integration

The digital twin as an integrator of all the data streams presented in this paper lays a sound foundation for:

The Ship Digital Twin framework captures both static and dynamic aspects of a ship's life cycle, enabling a holistic view of operational and maintenance needs

- Real-Time Monitoring
- Predictive Maintenance
- Simulation and Optimisation
- Enhanced Decision-Making

With comprehensive data at their fingertips, decision-makers can make informed choices that enhance safety, efficiency and profitability.

Conclusions

The implementation of Digital Twin technology in the maritime industry marks a significant advancement in ship operations and management. This paper introduced the Ship Digital Twin framework, leveraging a knowledge graph database to enhance improve data governance and provide tailored data views for various stakeholders, such as: class societies, flag states, ship operators and port authorities.

Central to this framework are "vessel visions" that enable actors to access and interpret relevant ship data effectively. By structuring ship data into a highly interconnected knowledge graph, the framework ensures precise decision-making and optimises life cycle costs.

The Ship Digital Twin framework captures both static and dynamic aspects of a ship's life cycle, enabling a holistic view of operational and maintenance needs. Recursive use of data from previous life cycles further enhances predictive capabilities and decision-making.

Data is structured according to stakeholders' specific requirements, ranging from structured data to semi-structured and unstructured data. This data is integrated into the knowledge graph and vector store model, allowing advanced processing using Large Language Models (LLMs).

Key data elements—ship position and ship status—are essential for the framework. By connecting to external data streams, the framework creates a comprehensive digital representation of the ship in her environment.

The data ingestion platform enables seamless integration of IoT sensors, external databases, and manual inputs, ensuring real-time processing and storage. This supports real-time monitoring, predictive maintenance, simulation, optimisation and enhanced decision-making.

In conclusion, the Ship Digital Twin framework integrates diverse data sources into a cohesive digital model, improving operational efficiency and safety while supporting sustainability and cost optimisation. As the maritime industry evolves, the Digital Twin framework will drive innovation, enhance data governance and ensure the longevity and efficiency of maritime assets.

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

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Marine Spatial Planning - Need for a Greater Push to Expedite MSP in India

Praveen Bakshi

Abstract

This article is about Marine Spatial Planning and the significance of its implementation in infrastructure development in and around coastal regions and inland waterways, with special emphasis on its relevance in India's context. The article outlines the process of Marine Spatial Planning, listing the steps involved in its development and implementation, its objectives, benefits and the key components. It also describes the current status of MSP in India, future course of action, the challenges in its implementation and the priority regions of the country in which Marine Spatial Planning needs to be implemented earnestly. The article also mentions the key institutions and agencies responsible for development and implementation of MSP in India.

Keywords: Spatial Data, Blue Economy, Large Marine Ecosystem, Marine Cadastral Systems, SAHAV

To ensure the sustainability and long-term success of the Government of India's ambitious projects aimed at maritime infrastructure development, such as the Sagarmala Programme, the Maritime India Vision 2030and the Maritime Amrit Kaal Vision 2047, it is essential to implement Marine Spatial Planning (MSP), at least in the regions covered by these initiatives.

India's strategic position on global trade routes, with a coastline stretching over 11,000 km, 14,500 km of potentially navigable waterways and a 2 million sq. km Exclusive Economic Zone (EEZ), offers significant opportunities for port-led economic growth in the Indian Ocean, stretching from Bay of Bengal in the east to Arabian Sea in the west. At the same time India faces increasing pressure from economic, environmental and social demands on its marine spaces because of these very features.

While all the aforementioned strategic initiatives by the Government of India, together with recent additions - Sagarmala 2.0 and Sagarmala Startup Innovation Initiative (S121), aim to harness this potential to boost international trade competitiveness by transforming the country's maritime sector, it is crucial to do so in conjunction with Marine Spatial Planning (MSP) in order to address the challenges and to ensure sustainability and continued purposefulness of these initiatives besides optimising the use of marine resources.

> *Marine Spatial Planning is a strategic approach to managing human activities in marine environments to achieve ecological, economic and social objectives*

Marine Spatial Planning is a strategic approach to managing human activities in marine environments to achieve ecological, economic and social objectives.

It is a scientific, participatory and policy-driven public process that guides where and when human activities occur in the ocean, aiming to reduce conflicts among uses, protect ecosystems and promote efficient and sustainable use of marine resources by analysing and allocating these activities spatially and temporally.

Main objectives of MSP are to:

- Balance various ocean uses such as shipping, fishing, tourism and energy.
- Protect marine ecosystems and biodiversity.
- Promote sustainable economic development of ocean resources.
- Minimise conflicts among users.
- Improve decision-making and governance in marine areas.
- Enhance resilience to climate change and environmental stressors.

MSP Process involves following typical steps:

1. Identify need and establish authority
2. Obtain and analyse spatial data
3. Set goals and objectives
4. Engage stakeholders
5. Develop spatial management plans
6. Implement plans
7. Monitor, evaluate and adapt

> *With international partnerships and strong policy backing, MSP holds great potential to support India's Blue Economy goals while protecting its rich marine biodiversity and ecosystems*

Key Components of MSP:

- Collection of Oceanographic, biological, economic and social data
- Engaging government, industry, NGOs and local communities
- Mapping & Zoning by identifying uses (e.g., fishing zones, shipping lanes, MPAs)
- Legal & Institutional Frameworks based on national and international maritime law
- Monitoring & Evaluation to ensure effectiveness and adaptability over time

MSP is being increasingly adopted worldwide as a science-based, participatory process to balance economic, social and environmental goals in marine areas. Many countries and regions have made significant progress in institutionalising MSP to support sustainable ocean governance, combat marine conflicts and advance the blue economy.

Over 125 countries / territories are engaged in MSP initiative and around 45 countries have legally adopted national marine spatial plans.

MSP coverage includes EEZs, coastal waters and transboundary marine regions (Large Marine Ecosystem - LME Projects e.g., Benguela Current, Coral Triangle, Caribbean Sea).

European Union has pioneered MSP with a binding EU Directive which mandates all EU coastal states to implement MSP. The focus areas include offshore renewable energy, fisheries, biodiversity protection and maritime transport.

Norway was among the first countries to implement MSP (Barents Sea, Norwegian Sea). It has integrated ocean management zones supported by strong scientific backing and serves as a model for India's MSP collaboration.

Other countries and regions that have adopted MSP include United Kingdom, United States (Coastal and Marine Spatial Planning - 'CMSP' under the National Ocean Policy), Australia (Great Barrier Reef: Integrated zoning plans protect biodiversity while allowing tourism and fishing), China, South Africa, Indonesia as well as small Island Developing States (SIDS), nations such as Seychelles, Mauritius and Fiji.

MSP in India

India is in the early but promising stages of Marine Spatial Planning. With international partnerships and strong policy backing, MSP holds great potential to support India's Blue Economy goals while protecting its rich marine biodiversity and ecosystems.

MSP is particularly important for India because of the following reasons:

- High population density along the coasts extending over a long stretch
- Rapid industrialisation and urbanisation
- Growth in shipping, ports and offshore energy
- Conservation needs of sensitive ecosystems (mangroves, coral reefs, etc.)
- Climate change impacts (sea-level rise, coastal erosion) and consequent disaster risk for coastal communities
- Rising marine conflicts among fisheries, energy, tourism and conservation interests

Highlights of MSP Progress & its Current Status in India:

India has partnered with Norway under Indo-Norwegian Integrated Ocean Management (IOM) Initiative. This initiative was signed in 2019 to implement MSP through joint efforts under Norwegian Ministry of Foreign Affairs and India's Ministry of Earth Sciences (MoES) and the National Centre for Coastal Research (NCCR). Union Territories Puducherry and Lakshadweep were chosen as Pilot Sites for developing India's first MSP frameworks.

These Pilot Projects focus on:

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- Mapping marine resources and ecosystems.
- Identifying priority zones for conservation, fisheries, tourism and infrastructure
- Integrating ocean-based economic activities like fishing, shipping, aquaculture and tourism.
- Capacity building and knowledge exchange.
- Promoting sustainable livelihoods
- Integrating climate adaptation strategies

In February 2023, Puducherry launched India's first MSP framework, marking a significant milestone in the country's coastal management efforts.

Development of a National Marine Spatial Planning Framework is underway. Draft guidelines are being prepared to help other Indian coastal states adopt MSP practices. MoES oversees the MSP initiative, with implementation support from the NCCR and the National Centre for Sustainable Coastal Management (NCSCM). These institutions collaborate with local authorities, such as Puducherry Coastal Zone Management Authority and international partners like Norwegian Environment Agency.

Other Agencies involved in MSP development & implementation are:

- Indian National Centre for Ocean Information Services (INCOIS)
- Ministry of Environment, Forest and Climate Change (MoEFCC)
- State Coastal Zone Management Authorities (SCZMA)

Integrating with the existing frameworks, MSP in India aligns with and complements:

- Coastal Regulation Zone (CRZ) Notification
- Blue Economy Policy Framework
- Integrated Coastal Zone Management (ICZM)
- United Nations Sustainable Development Goals (especially SDG 14 – Life Below Water)

Way Forward and Future Plans

The next steps involve scaling Pilot MSP Projects to all coastal regions using the frameworks developed in Puducherry and Lakshadweep to serve as models, strengthening marine spatial data infrastructure, integrating it with national maritime goals, ensuring stakeholder participation and building technical and institutional capacity.

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Regions That Need to Be Included in MSP in India

To ensure holistic and equitable marine governance, India must expand MSP to following additional ecologically sensitive, economically important and socially vulnerable regions:

1. Andaman and Nicobar Islands

Ecological sensitivity: These islands boast rich biodiversity, including coral reefs and mangroves.

Strategic location: Their position is crucial for maritime security and international shipping routes.

Blue economy potential: Opportunities in eco-tourism, fisheries and renewable energy are significant.

2. Gulf of Kutch and Gulf of Khambhat (Gujarat)

This region has a high concentration of **industrial activity**, ports (e.g., Kandla, Mundra) and **salt pans**.

It is also recognised as a **marine biodiversity hotspot**, featuring coral reefs and migratory bird habitats.

There is a risk of conflict between conservation efforts and development activities.

3. Mumbai Metropolitan Region (Maharashtra coast)

As one of India's **busiest maritime zones**, this region includes major ports and dense urbanisation.

It faces high levels of **pollution**, **shipping traffic** and risks associated with **coastal erosion**.

Integrated MSP is necessary to balance economic activities with ecological health.

4. Sundarbans Delta (West Bengal)

Home to the **world's largest mangrove forest** and a UNESCO World Heritage Site.

The region is vulnerable to **climate change**, **sea-level rise** and **cyclones**.

MSP is required for ecosystem-based disaster risk management and livelihood protection.

5. Chilika Lake and Odisha Coast

Asia's largest brackish water lagoon, critical for biodiversity and fisheries.

Threatened by aquaculture expansion, tourism and coastal erosion.

Strong candidate for MSP to ensure sustainable resource use.

6. Goa and Konkan Coast

Rich in **tourism**, **fisheries** and **biodiversity**.

Facing rising pressure from real estate development, mining runoff and cruise tourism.

MSP can help harmonise economic development with environmental integrity.

They face threats from overfishing, unregulated tourism, habitat destruction, pollution and climate change

7. Tamil Nadu and Andhra Pradesh Coasts

Highly exposed to natural disasters (cyclones, tsunamis).

Densely populated, with major ports such as Chennai and Visakhapatnam.

MSP is needed to support resilient coastal infrastructure and aquaculture zones.

8. Kerala and Karnataka Coast

Vulnerable to **sea erosion** and **urban sprawl**.

Major hub for fisheries with growing ecotourism.

MSP can support sustainable tourism and protect fragile ecosystems.

9. Nicobar Deep Sea Region (EEZ)

Part of India's **deep ocean mission** with high potential for **deep-sea mining**, **research** and **energy resources**.

MSP is essential for balancing scientific exploration and environmental stewardship.

Why these Regions Matter?

These regions have high population density and an economic dependence on coastal resources.

They face threats from overfishing, unregulated tourism, habitat destruction, pollution and climate change. Without integrated planning, there is a risk of resource conflict, environmental degradation and economic losses.

Challenges for MSP in India

- Fragmented governance across sectors and states
- Data limitations (quality, resolution, access) and lack of real-time information
- Capacity building needs at state and district levels
- Community engagement and local buy-in

Data collection is a foundational component of Marine Spatial Planning. It ensures that spatial decisions are based on accurate, science-based understanding of marine environments, uses and pressures

- Limited local-level capacity and trained personnel for MSP.
- Need for integration between national, stateand local coastal governance.
- Balancing economic development with ecosystem conservation, especially in densely populated coastal zones.
- Conflicting interests among stakeholders.
- Transboundary issues (e.g., between neighbouring countries).
- Difficulties in enforcement, compliance and monitoring of plans
- Climate change introducing uncertainty.

Data collection is a foundational component of Marine Spatial Planning. It ensures that spatial decisions are based on accurate, science-based understanding of marine environments, uses and pressures.

Data Infrastructure involves:

- Enhanced use of **GIS-based mapping**, **satellite imagery** and **marine resource inventories** to support MSP.
- Development of **marine cadastral systems** and marine-use zoning maps.

Various Tools & Platforms for Data Integration are:

- GIS Platforms: **ArcGIS, QGIS** for layering and spatial analysis
- Marine Data Portals:
  - **EU:** EMODnet
  - **Global:** GEBCO, Ocean Data Portal
  - **India: SAHAV Portal – under MoES**

SAHAV (*Spatial Analysis for Harmonized Allocation of Marine Space*) is India's first open-source web-based GIS platform for Marine Spatial Planning (MSP), developed by the NCCR under the MoES.

It was unveiled to coincide with the observance of World Oceans Day on June 8, 2025, at both the Monaco Marine Conference and the Third United Nations Ocean Conference (UNOC3) in Nice, France.

SAHAV is a Real Time Digital Ocean Data Portal that:

- Facilitates open access to oceanic data
- Promotes transparent, evidence-driven ocean governance
- Aims to support climate forecasting, marine resource tracking and disaster early warnings

The portal integrates scientific datasets and stakeholder inputs into layered maps and analytics. Validated through IndoNorway Pilots and recognised internationally, it's poised to underpin MSP rollout across India. It supports spatial analysis, visualisation and planning for sustainable and equitable use of marine and coastal resources.

> *SAHAV (Spatial Analysis for Harmonized Allocation of Marine Space) is India's first open-source web-based GIS platform for Marine Spatial Planning (MSP), developed by the NCCR under the MoES*

SAHAV assists in conflict resolution by identifying potential spatial issues and is designed for scalability nationwide. Ongoing updates and integration with monitoring systems ensure robust, actionable support for MSP initiatives. Having met the criteria including open licensing, privacy protections, documentation and system interoperability, it has been officially recognised as a Digital Public Good.

There is ongoing interest from international organisations, including the World Bank and the United Nations Environment Programme (UNEP), to support the expansion of MSP in India.

India's commitment to MSP reflects its broader vision of achieving sustainable development goals and promoting a resilient and inclusive maritime economy. Driven by international partnerships, India's MSP ambitions position it as a front-runner in ocean governance.

At the recently held Monaco Marine Conference on June 7 & 8, 2025, as part of the Third United Nations Ocean Conference (UNOC3), India underscored its deepening commitment to Marine Spatial Planning. On World Ocean Day, June 8, 2025, Dr. Jitendra Singh, Honourable *Minister* of State for Earth Sciences and Norway's Minister Åsmund Grøver Aukrust co-hosted a session on MSP aboard the historic Norwegian tall ship Statsraad Lehmkuhl, docked at Monaco's Port of Hercule.

> *There is ongoing interest from international organisations, including the World Bank and the United Nations Environment Programme (UNEP), to support the expansion of MSP in India*

India advocated for urgent global cooperation on marine conservation, highlighting SAHAV, blue economy investments and policy harmonisation with existing frameworks like ICZM and Sagarmala. Stakeholder integration and global partnerships were emphasised to advance SDG 14 (Life Below Water) and foster blue finance.

Dr. Singh reaffirmed India's ambition to scale MSP nationally, embedding it in overall blueeconomy governance via science-based, data-rich ocean management frameworks. He emphasised MSP's role as a crucial tool for resilient ocean governance and reasserted India's vision in collaboration with Norway

The **Monaco Marine Conference** served as a focused, action-driven lead-in to the **UNOC3**, helping spotlight innovation, like India's SAHAV portal and finance mobilisation. Together, they reflected growing global alignment on marine spatial planning, ocean-climate finance and science-driven governance. Dr. Singh referenced the Puducherry and Lakshadweep MSP Pilot Projects as proof-of-concept initiatives addressing coastal erosion, biodiversity and multi-sector stakeholder planning.

Besides Global Ocean Pact, India also advocated for speedy ratification of the BBNJ Agreement (Biodiversity Beyond National Jurisdiction). Hosting MSP talks within Blue Economy Financing Framework demonstrates India's alignment with global blue finance and SDG 14 commitments. Use of SAHAV Portal and data-rich Pilots show India is moving beyond policy rhetoric toward actionable tech integration.

References of the key Institutes and Agencies involved:

Ministry of Earth Sciences, National Centre for Coastal Research, National Centre for Sustainable Coastal Management, Indian National Centre for Ocean Information Services, Ministry of Environment, Forest and Climate Change, State Coastal Zone Management Authorities.

About the Author

Praveen Bakshi is a Marine Engineer with a long sea career spanning over 40 years, (> 30 years as Chief Engineer including over 15 years Oil Tankers). He has been a Faculty teaching Maritime subjects and now provides specialised support and technical expertise to the marine establishments worldwide. He is a Fellow of The Institute of Marine Engineers (India), Membership Number (F35010), Associate Fellow of The Nautical Institute (UK) and a Member of The Institute of Marine Engineering, Science and Technology (UK).

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Challenges in Polar Shipping

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Abstract

Simultaneous consideration of safety, eco-efficiency and cost-efficiency are the key requirements for strategic Polar vessels, involved in trade and scientific research. The article discusses the importance of Polar shipping, evolution of Polar Code, key design considerations for ice-class and ice-breaking ships, modern design methodologies and the matured risk assessment models for determining safe navigation speeds in level-ice and ice-floes. It is clear that, in addition to compliance with Polar ice-class rules, designers and ship owners need to quantitatively determine the bounds of ship's structural capabilities, its limitations in various ice environments and operational modes, and ensure route/location-specific navigation safety.

Introduction

Many countries are located in cold regions with significant ice cover during winter or for longer seasonal periods. These locations include the Arctic, the Antarctic, and other regions, such as the Baltic Sea. In order to navigate in these ice-covered regions, the first ice-breaking ships appeared in 1840's in Hudson River in the US and in the Elbe River in Germany, followed by dedicated ice-breakers that started operating in 1860's and 1870's from the harbours of St. Petersburg and Hamburg. The year-round navigation in the Baltic started in 1877 with the introduction of the ship Express-II sailing between Turku and Stockholm. In 1890, Finland developed the first steam-powered ice-breaker ship Murtaja with a capacity of 1600hp.

Figure.1. Evolution of early ice-breaker ships

During 1950s, Lena- and Amguema-series of ships capable of navigating in ice-covered oceans were developed by the Soviet Union for enabling Arctic trade. It was in 1957, as a major technological breakthrough, Lenin, the first nuclear-powered ice-breaker was launched by Russia **(Figure.1).** Following these, several series of Arctic ships were built to Soviet and Russian owners (e.g. Norilsk and Norilsk Nikel-series), Finnish owners (Lunniseries), the Canadian ships MV Arctic and MV Umiak. Later in 1980s, double-acting ice-breaking ships of travel forward in open water and thin ice, but turn around and proceed astern in heavy ice conditions were developed. These ships can operate independently in severe ice conditions without icebreaker assistance but retain better open water performance than traditional icebreaking vessels. Over the past 13 decades, right from Murtaja through double-acting ships, till Arktika class, ice-breakers were based on several technological innovations.

Recent interest in these polar vessels is due to the expected favorable ice conditions caused by the warming of the Arctic, which is estimated to be 2-4 times faster than the global average. The receding sea ice in the Arctic is enabling an increase in shipping across the northern polar region, connecting Asia and Europe by trans-Arctic routes **(Figure.2).** The Northern Sea Route (NSR) is a promising alternative compared to the route via the Suez Canal – the leading maritime transport highway connecting Europe and Asia. The improving conditions due to melting ice, makes the NSR attractive for shipping. Around 40% shorter distance, melting ice, and upcoming ice-breaking services are the factors that make the NSR more eco-efficient than the Suez Canal route for shipping between Western European and Eastern Asian ports.

Figure.2. Shipping routes in the Arctic region

Motivated by the Council of Managers of the National Antarctic Programs (COMNAP) project, multiple polar ships are realised, including BAP Carrasco (PC7), L'Astrolabe (PC5), RRS Sir David Attenborough (PC4), RV Kronprins Haakon (PC3), MV Xue Long 2 (PC3) and RSV Nuyina (PC3). An assessment on capabilities based on key characteristics of 18 Polar Research and Supply Vessels (PRSV) (including ice-breaking, logistics, science research and ship size) built during the last two decades depicted in radar diagram, shows the sustainability in Polar ship designs and operations, capable of catering both research and commercial activities in the Polar regions **(Figure.3, 4).** Hitherto, there are ~ 40 ships classified as ice-breakers currently operated by 12 countries including Argentina, Australia, Canada, China, Finland, Germany, Japan, Norway, Panama, Russia, Sweden, and the United States.

Figure.3. Representative ice-breaker ships used in Polar

Major nuclear-powered ice-breakers of Russia including Arktika, Sibir, Let Pobedy, Taymyr, Vaygach and Yamal are in the range of 150-175m long, 21000-33000MT, 8-10m draft, open-ocean speed of 22 knots and capable of cruising in 2 knots in 2.8m thick ice. Ice-breaker Arktika with 75 crew capacity has an installed power of 350MWt, 3 x 20MW shafts, endurance of 7 years for nuclear fuel and 6 months for provisions. Many countries engaged in polar research are commissioning PRSVs. India is also in the process of acquiring a state-of-art multi-disciplinary Polar Research Ship with ice-breaking capability (PC5) which is ~130m long to cater to all scientific and logistics needs of Indian polar programs.

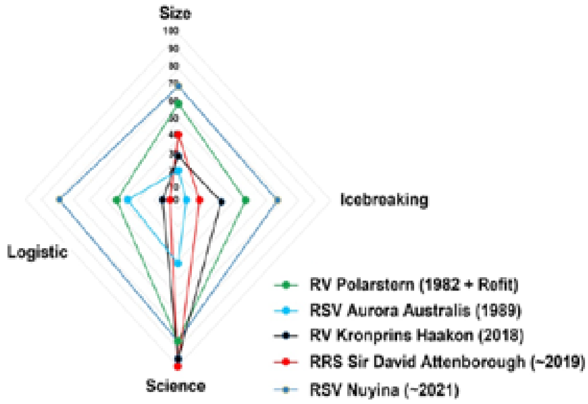

Figure.4. Key characteristics of modern Polar ships

Polar code (PC)

Simultaneous consideration of safety, eco-efficiency and cost-efficiency are the key requirements for sustainable polar shipping. This demands appropriate ship configurations, alternate green energy sources and novel technologies. The environmental and human factors leading to safety hazards specific to Polar Regions is summarised in **Figure.5.**

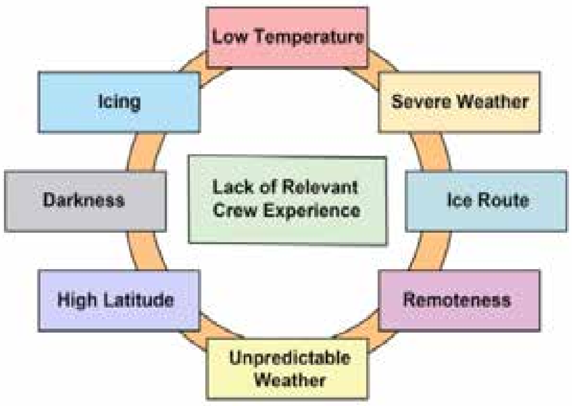

Figure.5. Major challenges in Polar shipping

Melting glaciers and multi-year ridged ice (a type of sea ice that has survived at least one melt season and forms into ridges), breaks down into smaller pieces of thick ice and drift into areas where favorable ice conditions are expected, makes sea ice unpredictable during ship navigation. Hence operation in these complex ice conditions require ships to have specific ice-breaking hull shapes, enforced ship structures, and high engine power to provide satisfactory safety and performance. In order to ensure safe navigation in these challenging environments, the IMO's International Code for Ships Operating in Polar Waters (Polar Code/PC) is mandatory under both the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL).

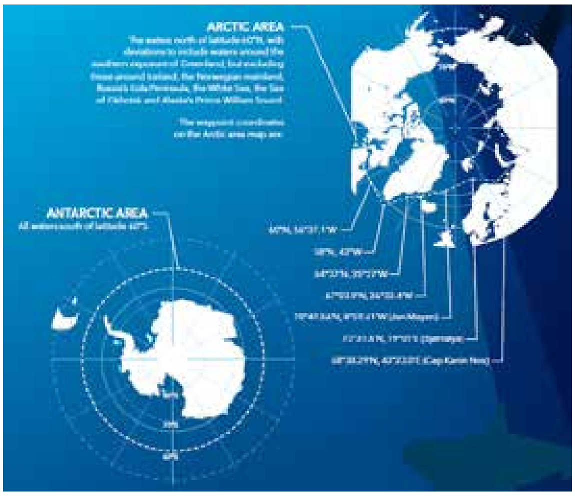

Figure.6. Regions covered under the Polar Code

To ensure safety, PC entered into force in 2017 covering full range of shipping-related matters relevant to navigation in waters surrounding the two poles (the areas covered by PC shown in **Figure.6)** including ship design, construction and equipment; operational and training concerns; search and rescue; and, equally important, the protection of the unique environment and eco-systems of the polar regions **(Figure.7).**

Figure.7. Regulation for Polar ships

Design considerations for Polar Ships

The design of Polar ships could be traced back to the design of the expedition research ship Fram (1893-1866, used in Nansen's Polar expedition) that had a rounded hull form helping her to lift up onto the ice. The force caused by the horizontal ice pressure has a component normal to hull, aiding the ship to break the ice due to its weight and move forward, which forms the basis for all Polar ships. The Finnish ice-class rules issued in 1932 introduced ice classes 1A, 1B and 1C for ships strengthened for navigation in the Baltic Sea, Ice Class 2 for ships classified for unrestricted service, but not strengthened for navigation in ice, and Ice Class 3 for other ships. Later in 1948, through international collaboration, IMO enhanced the ice-class rules and issued regulations and standards enabling safer vessels and to ensure increased probability of rescue when operations fail. The construction and operational needs for Polar ships, including categorisation of operational capability is summarised in **Table.1.**

Table.1. Construction & operational needs for Polar ships

Feature	Operating capability
Design & Construction	Ship category (A, B, &C), Intact stability, Materials, Structure
Equipment	Windows on bridge, lifeboats, clothing, ice removal aids, fire safety
Operations	Navigation, Training, Search & Rescue (SAR)

The design considerations for polar ships based on challenging environmental conditions, so as to achieve safety, eco-efficiency and cost-efficiency is represented in **Figure.8.** The importance of polar-centric hull geometry, propulsion, maneuvering, flood mitigation and emergency evacuation systems are discussed.

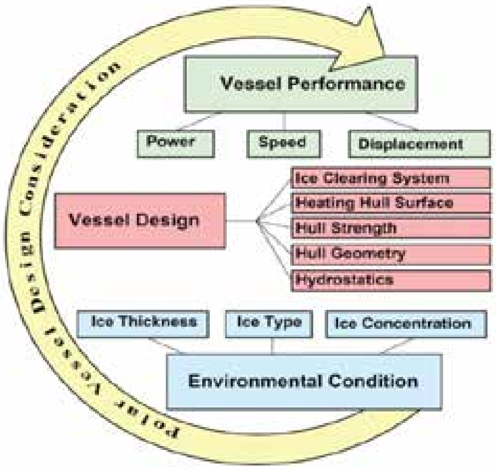

Figure.8. Design consideration for Polar ships

Hull geometry

The risk of damage to the hull of a ship operating in ice depends on many factors which include the ice conditions (thickness, strength and concentration), ship structural specifications (hull shape, scantlings and structural arrangement) and the operational profile (speed and manoeuvring). To overcome the risks due to floating ice, Polar ship feature exclusive hull design, high-power engines, ice-clearing systems and heated hull surfaces. The hull made of thick steel shall withstand low temperatures and ice pressure, their sloping sides and stern enable maneuvering in icy waters, the reinforced bow cuts through the ice, the ice-belt acts as a reinforcement band around the waterline providing extra strength where the ice impact is high, the V-shaped bow breaks the ice and move it away from the ship, and the S-shaped stern line with a wedge extends from the bottom to the stern line.

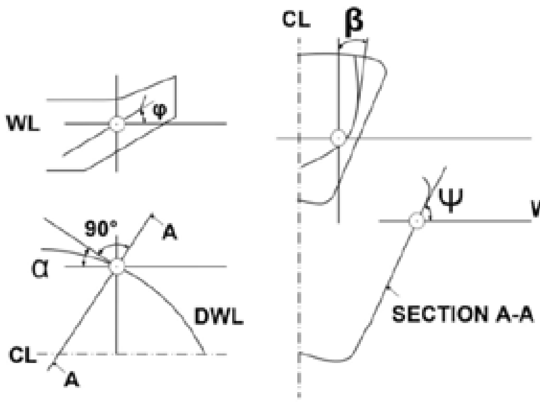

Figure.9. Definition of hull angle in Polar ships

The design of structure for ice-breakers and other ice-capable ships requires knowledge of the magnitude of ice loads, which are influenced by hull shape, displacement, power, speed, ice confinement, and ice type. The bow shapes for ice-breakers are described by the stem, flare, buttock, and water-line angles **(Figure.9).** The hull shape of the 19th century icebreakers were characterised by a very small buttock line angle φ at the stem. Buttock lines and waterlines were rounded and the sides were inclined (β>0). The rounded stem developed quite late (in the 1980's) had a sharp bow favourable for ice-breaking. Their hull lines design is to make the flare angle ψ as small as possible. These angles contribute to the ice-breaking, submergence, and ice-clearing efficiency. Recent trends in the design of ice-breakers are to increase flare angles, to reduce water-line angles, and to reduce stem and buttock angles.

The ship's hull is divided into areas reflecting the magnitude of the ice-induced loads that act upon them. In the longitudinal direction, there are four regions, Bow (forward region), Bow Intermediate (a transition between the forward and mid-vessel regions), mid-body (mid vessel region) and stern (aft region). The ship's structure must be designed, and arranged, to withstand the ice loads imposed globally and locally. The ice load experienced by a ship's hull varies vary between the hull areas **(Figure.10). The bow area experiences the highest loads, while the ship bottom (below the ice) will generally experience lesser loads.** The local structure must resist failure caused by bending, shearing and buckling. Although bending failure has traditionally been considered, the most likely failure mode, based on the experience gained from Arctic operations indicates that frame buckling and tripping are more critical.

In order to overcome these failures, structural designs require proper selection of hull materials. The primary groups of steel used in vessel construction are normal strength and high-strength steels (referring to their minimum yield strength). Within each of these groups, there are several grades of steel based on chemical composition and mechanical properties, mainly their resistance to brittle fracture due to low temperatures and high mechanical loading conditions. At low temperatures, the ductility and fracture toughness decreases, the steel becomes brittle, increasing the likelihood of a catastrophic brittle fracture. Such fracturing is more frequent above the water-line where steel is exposed to very low air temperatures.

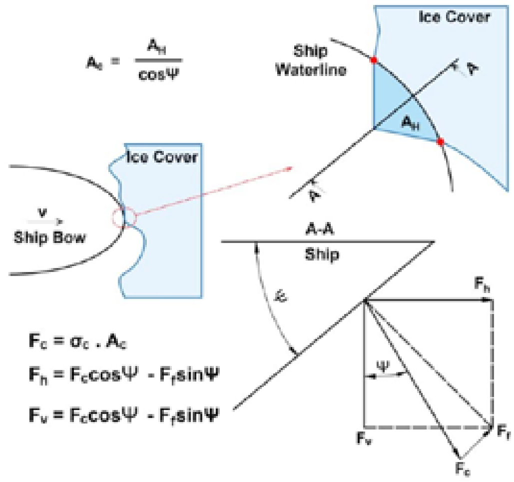

Figure.10. Loads experienced by ice-breaking ships

The selection of a mid-body shape has to consider its effect on resistance, maneuverability, construction cost, and the required deadweight. The mid-body shall be characterised by flare angle (over the full-depth or locally), parallel mid-body, and longitudinal taper. The stern design on ice-breaking ships is controlled mainly by the number of propellers, which is a function of the required power and operational requirements. The stern that allows the broken ice pieces to move upward to the surface well ahead of the propeller must provide protection to the rudders and propellers. The conventional stern is rounded to provide good ice-breaking astern performance, and is usually fitted with an ice horn to protect the rudder.

Propulsion and maneuvering system

Propulsion systems for ice-going vessels must be reliable, flexible with a view to redundancy, maintainability and have high power-to-weight and power-to-space ratios. The two dominant propulsion systems in ice-going ships are diesel-electric transmission with fixed-pitch propellers (typically installed on ice-breakers (the first diesel-electric ice-breaker was the Swedish IB Ymer in 1933), and diesel-mechanical transmission with controllable-pitch propellers. Ships not required to break ice would normally have a diesel-mechanical transmission, with or without controllable-pitch propellers. The bow propellers were introduced in the ice-breakers during the end of 19th century (first European bow propeller

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Officers are required to hold a Certificate of Competency and a Certificate of Proficiency for Basic Training for Liquefied Gas Tanker Cargo Operations and at least three months of approved sea going service on Liquefied Gas Tankers within the last sixty months on liquefied gas tankers, or at least one Month of approved onboard training on Liquefied Gas Tankers in a Supernumerary capacity, which includes at least three loading and three Unloading operations and is documented in an approved training record book as specified in section B-V/1 of the STCW Code.

Course Date: 3rd – 13th November 2025

For registration, CLICK HERE

FOR MORE INFORMATION please email to **training@imare.in** or **contact on M: 8454847896/ 022 2770 1664 & 27711663** ice-breaker is the Finnish Sampo). The bow propeller improves the ice-breaking capability by reducing the forces required to break the ice and by reducing friction. Recently, bow propellers have been made superfluous by the introduction of Z-drives (azimuthing propulsion units), the first ice-breaker with Z-drives was the Finnish multi-purpose icebreaker Fennica in 1993.

The most recent development for ice-breaker propulsion systems includes submerged azimuth pod propulsion motors, which are proving to be very effective for both ice-breakers and ice-breaking cargo vessels **(Figure.11).** By eliminating the need for a rudder, these systems make ships more maneuverable, and at the same time, they remove the threat of rudder damage. The Finnish PC4 ice-breaker Polaris and Arctic shuttle tanker Shturman Albanov equipped with Azipod main propulsion is the first ship certified to comply with Polar Code requirements **(Figure.11).** Azipod is in more than 60 ships operating in Pechora Sea, Kara Sea, Ob Bay and Yenisei River.

Figure.11. Podded azimuth thrusters in ice-breaking ships

In Polar ships, sufficient protection of propulsion and maneuvering units are achieved by providing adequate structural strength to the exposed components or by managing the structural loads that are exposed to ice. Increasing the scantlings of the propeller blades and shafts reduces the propulsion efficiency and increases the construction cost, while lower values result in increased damage frequency and consequences that demands appropriate trade-off between hydrodynamic efficiency and structural strength.

Recent analysis of damage to steering systems of ice-going vessels has shown that over half the failures have been to rudder stocks (~20% to the steering gear, and another 20% to pintles and bushings, keys, and bearings). The highest loading on steering systems occurs during astern operations. The rate of rise of load can be so rapid that pressure relief valves for open-water operation are not sufficiently fast and allow the ice load to reach excessive levels before they become effective. The stern arrangement in most ice-breakers offers rudder protection with an ice horn located directly above and aft of the rudder. Rudder stops fitted to the hull stops the rudder at least 2º before the maximum steering gear travel, offer additional protection.

> ***The conventional stern is rounded to provide good ice-breaking astern performance, and is usually fitted with an ice horn to protect the rudder***

Cooling system

There is potential for ice and slush to enter sea bays or sea inlet boxes, blocking sea-water flow to the cooling system. This problem is encountered by a majority of ships entering ice-covered waters, especially when in ballast at light drafts. If water cannot be obtained for the cooling system, the main engines will not perform properly and may overheat causing the engines to shut down, or getting damaged. The design of ships that operate in ice prevents the cooling system from becoming blocked by ice by maintaining essential seawater by using inlets situated as low and as far aft as possible near the centerline or using sea boxes that are fitted on each side of the vessel, deeply submerged as possible having an area open to the sea of 5-6 times the total area of pump suctions served by the sea bay.

Flood mitigation and emergency evacuation

The ship's survival time must be infinite for all possible flooding conditions through an effective flood mitigation system, primarily achieved by compartmentation (passive means) and water tight doors & valves (active). For each damaged condition, the survivability (sinking/capsising) is calculated based on the GZ curve (that indicates the transverse distance between the Center of Gravity (CG) and Center of Buoyancy (CB) in a condition when the ship is heeled to a certain angle) for which PC prescribes an icing allowance in terms of an assumed amount of ice accumulated on its exterior surfaces. To fulfil the intact stability requirement, the PC requires that an allowance for icing be made in the ship's stability calculations and this allowance is described in the ship's Polar Water Operational Manual (PWOM).

Furthermore, to support winterisation (that includes adding adequate thermal insulation, heat tracing cables, special lubricants, and designing heating systems to prevent freezing and maintain operational efficiency). the ship must have effective means to prevent or remove snow and ice accumulation such that it does not exceed the values given in the PWOM. The PC prescribes a minimum icing load of 30 kg/m^2 on exposed weather decks and gangways, 7.5 kg/m^2 for the projected lateral area of each side of the ship above the water plane, and an additional allowance for the projected lateral area of discontinuous surfaces and small objects **(Figure.12).**

The heating power capacity for anti-icing and de-icing shall not be <300 W/m² for open deck areas, gangways and stairways, ~200 W/m² for superstructures, and ~50 W/m² for railings with inside heating. The ice-phobic coatings on topside weather surfaces reduce ice accretion lower the adhesion strength of ice and may be considered as enhancements to other ice removal methods, such as mechanical, steam, electro-thermal or electromechanical. **Figure.13** shows the reported trends in the ice accretion rate under various harsh environmental conditions. Other features of polar ships, mainly ice-breakers include redundant high-power engines to navigate through ice, ice-clearing systems, air bubbling systems to reduce friction between the ship and the ice, heated hull surfaces to prevent ice from sticking to the hull.

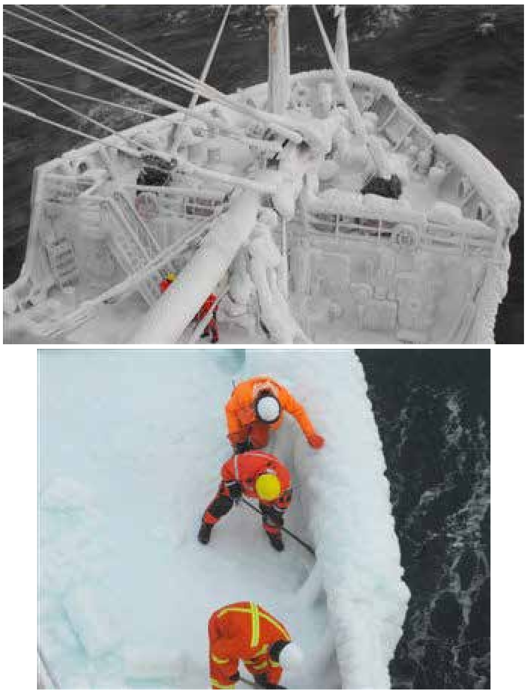

Figure.12. Crew removing ice from bulwarks, ice build-up on forecastle

In case of emergency, the system must enable all persons on-board to escape the ship and to survive until the help arrives, which depends on escape routes, embarkation arrangements, survival crafts, life-saving apparatus and efficiency of the survival trainings. Regarding the post-evacuation survival time, the PC requires that the survival craft, together with the required equipment, provide evacuation for the maximum rescue response time, which must not be less than 5 days.

The ice-phobic coatings on topside weather surfaces reduce ice accretion lower the adhesion strength of ice and may be considered as enhancements to other ice removal methods, such as mechanical, steam, electro-thermal or electromechanical

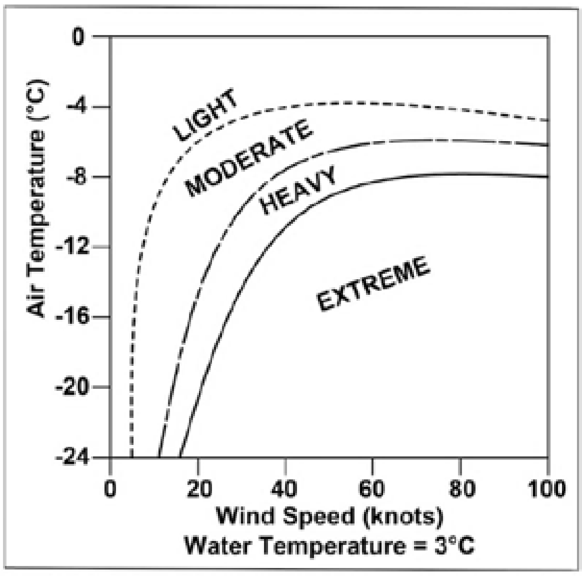

Figure.13. Trends in the ice accretion rate in Polar conditions

An "ice-class" refers to a designation given to a ship indicating its ability to navigate through ice, essentially a level of ice-strengthening in its hull, while an "ice-breaker" is a specially designed ship with significantly enhanced capabilities to break through thick ice, often used to clear paths for other ships in icy waters. As design guidance, there are 7 PC standards **(Table.2),** which are described in IACS. In accordance with IACS, the required PC standard is to be determined based on the maximum ice conditions in which a ship is supposed to operate. For instance, PC4 is required for a ship that is expected to operate year-round in thick (>1.2 m) first-year ice, whereas PC5 is sufficient for a ship that is expected to operate year-round in medium thick (0.7 – 1.2 m) first year ice. The PC6-PC7 is ice-strengthened ships, PC4-PC5 is ice-capable, and PC1-PC3 ships are heavy ice-breakers.

Table.2. Classification of ships based on operational capability

Ice class	Operating capability
Ice breakers	
PC1	Year-round operation in all polar waters
PC2	Year-round operation in moderate multi-year ice (>120 cm) conditions
PC3	Year-round operation in second-year ice (>120 cm), which may include multi-year ice inclusions
PC4	Year-round operation in thick first-year ice (>120 cm), which may include old ice inclusions
PC5	Year-round operation in medium first-year ice (70–120 cm), which may include old ice inclusions
PC6	Summer/autumn operation in medium first-year ice (70–120 cm), which may include old ice inclusions

PC7	Summer/autumn operation in thin first-year ice (30–70 cm), which may include old ice inclusions
Ice class	
ICE-1A	First-year ice to 1.0 m
ICE-1B	First-year ice to 0.6m
ICE-1C	First-year ice to 0.4 m
ICE-C	Light ice conditions

Modern design methodologies for Polar ships

Simple compliance with ice-class rules does not provide a full representation of the ship's structural capabilities or limitations in various ice environments or operational modes. Additional analyses are often carried out by designers, ship builders and owners to quantitatively place bounds on the ships' structural and ice navigational capabilities. Computing the loads on the ship structure and propulsion system through ship-ice interaction study is a complex process, which is stochastic in nature, that requires due consideration of route/location-specific ice parameters **(Table.3).**

Table.3. Properties of ice

Ice parameter	Value
Density (kg/m³)	900
Young's modulus (GPa)	5
Poisson's ration	0.3
Initial compressive strength (MPa)	5.8
Initial tensile strength (MPa)	0.58
Plastic hardening modulus (MPa)	6
Effective plastic failure strain	7.0

Model tests to estimate the ship-ice resistance for Baltic ice breaker ship Perkun was first reported from Russia in 1950s, in which wax was used in place of ice. During late 60's model tests on Antarctic ice-breaker ship Sharse showed that the resistance almost doubled as hull-ice friction coefficient doubled from 0.1 to 0.2, which was examined based on a set of parametric equations for various bow forms. Later studies were based on semi-empirical formula to calculate the ice resistance encountered by the ship (below equations), where Frp denotes the ice Froude number, hi is ice thickness, C is the ice concentration, g is the acceleration of gravity, Rp indicates the ice resistance, Cp signifies the ice force coefficient, B and ri are the ship beam and the ice density, and kc, b, and n are constants relevant to ship parameters.

$$\mathbf{Fr_p = V / \sqrt{g h_i C}}$$

$$\mathbf{R_p = 0.5 C_p \rho_i B h_i V^2 C^n}$$

$$\mathbf{C_p = k_c Fr_p^{-b}}$$

During 1970-80, the ice load parameters were computed based on Kurdyumov and Kheisin's velocity-dependent hydrodynamic model for local contact pressure coupled with Popov-type collision mechanics. In post-1990, probabilistic approaches and hydrodynamic model of ice-solid body impact combined with Popov collision mechanics were adopted. It involved ice collision forces, considering structural deformation, assuming a linearised plastic component of the structural response by solving a system of motion equations in the time-domain and adopting a pressure-area model. In such studies, a regression analysis of grillages subjected to point loads using the non-linear finite element analysis (FEA) method was used to develop this plastic component.

Since last two decades, the Polar UR ice load model is being used based on a ship-ice collision scenario. Loading parameters are derived considering ship operational scenarios, hull geometry, the strength of ice and its failure modes. The selected design scenario is a glancing impact with an infinite ice edge. The model incorporates Popov collision mechanics, which simplifies the ship-ice collision to a single degree-of-freedom (DoF) problem. This simplification is justified based on the assumption that the duration of the impact event is short and its location along the hull does not change much. The collision model is coupled with a process-pressure area relationship for the formulation of local pressures. It follows a coherent process to fully describe the ice load patch in terms of pressure, force, line load, load patch width and load height. The structural limit states adopted by the Polar Rules provide a set of analytical expressions for the capacity of primary stiffening members. These models were derived on the basis of energy methods and make use of plastic limit analysis. They were validated against extensive numerical simulations and physical experiments.

Recently used approach is to couple Computational Fluid Dynamics (CFD) with DEM (discrete element model), which allows for fully non-linear fluid solutions. It is a very mature approach to model hydrodynamic problems. A CFD and DEM approach is used to simulate scenarios when ship is advancing in ice floes, ship-ice collisions occurring in the bow area, and the ice floes being pushed aside and rotate within the wake region. As described in **Figure.14,** estimating the extreme bow stresses should take into consideration route-specific probabilistic ice loads (e.g. 100-year max load) based on the ships average annual ice exposure, determined in terms of the annual average distance a ship operates in various ice conditions. (e.g. thin, medium, and thick first-year, second-year, multi-year, or brash ice). Once the probabilistic extreme loads have been determined, they can be used as input for direct analyses (e.g. FEM) to determine the required level of ice strengthening, or to verify that a design is determined in accordance with the PC rules provide a sufficient level of strength.

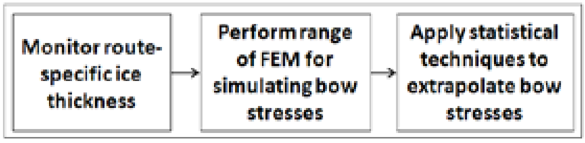

Figure.14. Modern approach to polar ship bow stress estimation

As a ship enters a level ice field, the initial contact takes place at the very front of the bow, followed by the ice being crushed by the penetrating ship hull. Load levels generated in the crushing process strongly depends on the bow geometry, especially the flare angle, called the ice-breaking angle. The crushing force rises with the increasing contact area, until its vertical component has reached the breaking capacity and caused bending failure of the level ice sheet at a certain distance from the contact zone. Once the probabilistic extreme loads are determined, they can be used as input to FEM to determine the required level of ice strengthening or verify the design compliance with IACS rules. **Figure.15** shows a typical FEM used for determining the ice loads. An increase in the hull scantlings results in a lower damage frequency, and there by lower maintenance and repair costs. On the contrary, it increases the construction costs and fuel costs. Thus the trade-off design between damage frequencies, construction and fuel costs needs to be identified.

Figure.15. FEM to determine structural loads in ice vessels

Based on reported DEM results, the force created by an array of ice floes on a ship beam increases with increased ice concentration, ice drift speed and the width of the beam. During the process, the load varies linearly with the drift speed and beam width, and exponentially with ice concentration. Ice loads in level ice and brash ice condition present a characteristic of periodicity, while ice force fluctuates randomly in broken ice because of non-uniform distribution of ice foes. It is also reported that ice resistance has a linear relationship with the ship speed. The achievable speed in broken ice condition is almost 3.5 times of that in level ice with the same thickness. With the same thrust power and the same speed, in brash ice condition, the ship can transit in ice 2.7 times thickness of that in level ice condition. It is reported that Lindqvist formula is suitable for estimating ice resistance in level ice condition, Zuve & Dobrodeev formula for broken ice scenarios, and Dobrodeev formula in brash ice conditions.

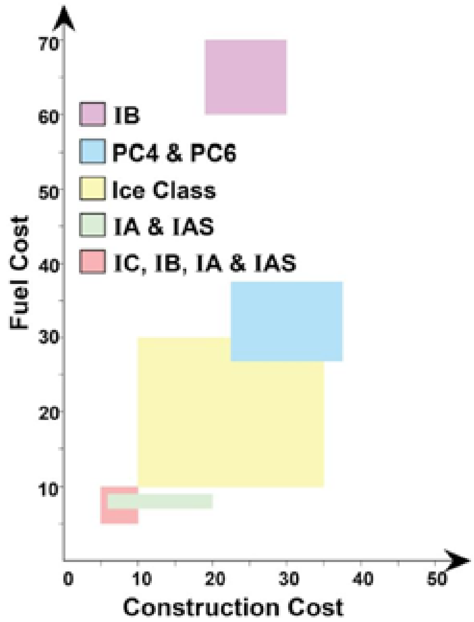

Figure.16. Relatively higher costs incurred by Polar Ships over conventional ships described by various agencies

Fuel consumption and corresponding air emissions of a ship operating in ice are higher than that in open waters. Moreover, the ice-breaking hull shape reduces ice resistance but may also reduce hydrodynamic efficiency by >30% and deteriorate sea-keeping performance. The latter can result in significant delays in high waves, accompanied by reduced safety and habitability of a ship, which is especially important for cruise ships. Sometimes rolling of ice-capable ships is so uncomfortable that captains prefer to bypass open waters by breaking through the closest ice routes. As a result of the trade-off design, ice-classed ships are reported to have ~11% more hull mass, ~13% more main engine power and ~13% less dead-weight capacity than ships without ice-class. Another design issue is relevant for ships operating in shallow polar waters, in which the limited draft of ship constraints maximum propeller diameter. As a result, a propeller does not provide enough power to break the ice. The latter may require a wider hull to incorporate an additional propeller. The wider hull, in turn, could deteriorate the ice-breaking performance of a ship. Hence, using ice-breaker assistance on a demand basis is a way to improve the performance of a ship in ice for a limited time without sacrificing its open-water efficiency. The experiences reported by the shipping industry in constructing and operation (fuel costs) of Polar ships described by various agencies are summarised in **Figure. 16.** This indicates that a proper trade-off design from eco-friendliness and cost economics is required, based on the route in which the polar ship is likely to operate.

Safe navigation in Polar seas

The earliest concepts for safe navigating speeds in Polar seas were postulated by Russian scientists during 1960-

1970 by developing transportation regulations for ships operating in the Russian Arctic. The Ice Passport (often referred to as the Ice Certificate) was first introduced in the mid-1970s. One of its major components is the regulation of speed to mitigate the risk of hull damages due to ice. They defined the safe limit speed as "*the maximum speed under given ice conditions which ensures safe navigation*", is depicted by simple diagrams **(Figure.17).** In the late 1990s, Canadian authorities published methodology (first applied to CCG Pierre Radisson) about the ice-load modelling procedures and the formulations to express the load-bearing capacity of framing members. Hence, route-specific ice thickness data is directly needed for the ship design and navigation analysis.

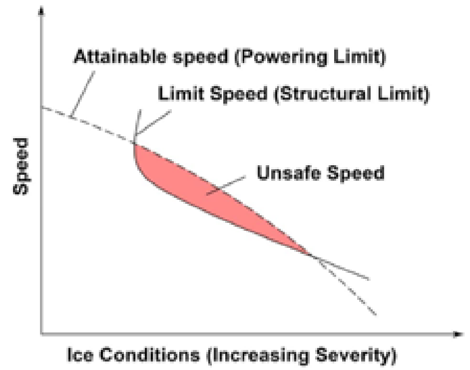

Figure.17. Determining safe navigation speed

Presently, polar navigating ships utilise the ice conditions en-route modelled based on the long-term statistical ice charts published by the Arctic and Antarctic Research Institute (AARI). Sea ice charts are based on ice observations made from synthetic aperture radar (SAR) satellite imagery, optical imagery and other ancillary data. Trained ice analysts use a standardised methodology to classify imagery according to observed ice concentration and stage of ice development. Stage of development relates to new ice, young ice, thin first-year ice, first-year medium ice, first-year thick ice, old (multi-year) ice, and glacial ice. As a typical example, the equivalent ice thickness calculated based on Central Marine Research and Design Institute (CNIIMF) is,

$$h_{eq} = c(h_i + 0.25bh_i + k_{sn}h_{sn})$$

where c is the ice concentration, h_i is the level ice thickness, b is the share of ridged ice, the integer ranging from 0 (0%) to 5 (100%), k_{sn} is 0.33 if $h_{sn}<0.5$ or 0.5 otherwise, h_{sn} is snow thickness.

Normally, ice data (equivalent thickness) with a temporal resolution of a month are analysed for each segment of the route considered. The concept of equivalent ice thickness allows reducing many ice characteristics to one parameter, representing the complexity of ice conditions. Consequently, the ice data is processed to obtain the frequency distribution of ice conditions with specific equivalent ice thickness for each route segment in a specific month. As an example, for a segment 5–6 in May reported is shown **(Figure.18).** Based on AARI, it is reported that the ice-breaker ship Xue Long 2 (measuring 122m long, 22m beam, 8.3m draft and displacement of 14300 T) is able to break through 1.5m thick ice at a maximum speed of 3 knots.

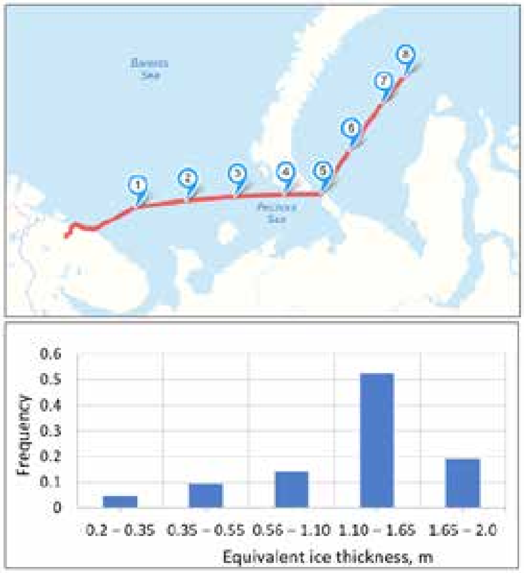

Figure.18. Computed equivalent ice thickness

Sea-ice formation and advection by surface currents, promote significant variability in ice concentrations and thickness over local and regional spatial scales. More than 58 besetting incidents took place on the NSR over the past decade, with at least 18 ships were beset during the month of November alone. The MS Explorer Canadian cruise ship stuck submerged off-Antarctica, Bulbous bow

"The Polar Operational Limitations Assessment Risk Indexing System (POLARIS) is a Decision Support System (DSS) that uses the ship's actual ice class and the actual ice regime encountered to determine a Risk Index Outcome (RIO)"

of M/V Zélada Desgagnés damaged by ice in Frobisher Bay is shown in **Figure.19.** Some were frozen for weeks and required ice-breaker support before they could resume their voyage. Thus, considering the importance of navigation safety, over the past decade, the number of ships operating in the Arctic Ocean as defined by the International Code for Ships operating in polar waters increased by 25%.

Figure.19. Incidents encountered by Polar ships

The Polar Operational Limitations Assessment Risk Indexing System (POLARIS) is a Decision Support System (DSS) that uses the ship's actual ice class and the actual ice regime encountered to determine a Risk Index Outcome (RIO). The POLARIS system was developed in concert with national administrators from Canada, Denmark, Finland, Russia, and Sweden in response to a draft of the Polar Code that assumed 100% ice coverage of one ice type, while in reality a 100% ice coverage of one ice type is very rarely met. The POLARIS uses Risk Values (RVs) based on the ice type and the ship's classification to calculate a RIO. The RIO is a single value representing operational risk for a PC ship travelling through an area with a given ice regime, or a combination of ice types within the region of interest. The metric was originally developed as an Ice Numeral (IN) for the Transport Canada Arctic Ice Regime Shipping System (AIRSS). The AIRSS system was later updated to align with the POLARIS, which reflects capabilities of the PC classification system.

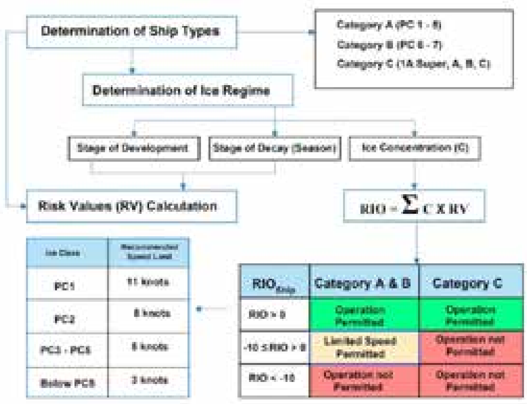

Figure.20. Principle of navigation risk computation

The RV ranges from -3 to +3 for PC 1–7 ships, indexed to a ship's structural characteristics determining its ability to navigate ice of a certain developmental stage. Positive risk values are used when a ship is structurally capable of navigating a particular ice type. The negative values are used when a ship is not structurally capable. The methodology for computing the RIO and safe speeds under various conditions is shown in **Figure.20.** POLARIS states that when sea ice concentration and ice thickness are above certain thresholds, navigation speed will inevitably be affected and may even need to be detoured. The sea-ice charts from US National Ice Center are also used by other agencies for RIO computations. Ice charts consolidate all available information on ice cover using the "ice egg" diagram, which in most sea areas will be developed using WMO principles and terminology **(Figure.21).** The likely risks on various classes of Polar ships under various environmental conditions are represented in **Figure.22.**

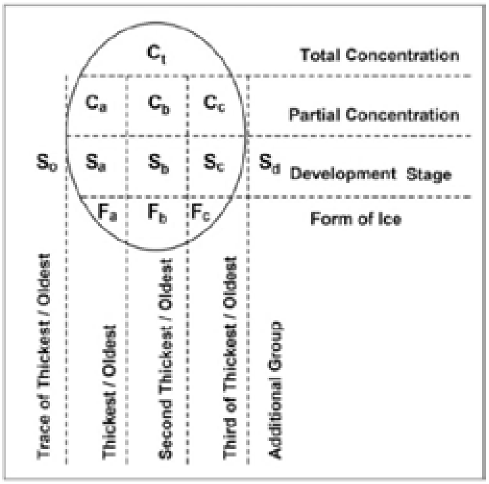

Figure.21. Egg diagram representing ice concentration factor

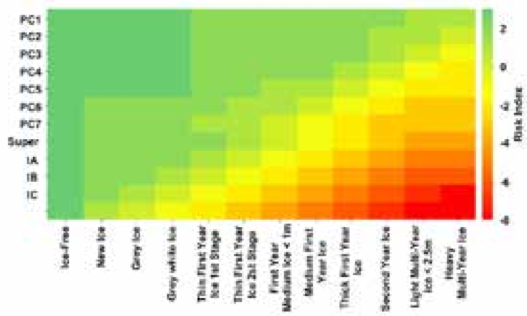

Figure.22. RIO for various categories of polar ships

Abbreviations

AARI	Arctic and Antarctic Research Institute
AIRSS	Arctic Ice Regime Shipping System
CB	Centre of Buoyancy
CCG	Canadian Coast Guard
CFD	Computational Fluid Dynamics
CG	Centre of Gravity

COMNAP	Council of Managers of National Antarctic Programs
CNIIMF	Central Marine Research and Design Institute
DEM	Discrete Element Model
DoF	Degree of Freedom
DSS	Decision Support System
FEA	Finite Element Analysis
FEM	Finite Element Method
GZ	Righting Lever Curve
IACS	International Association of Classification Societies
ICSPW	International Code Ship & Polar Waters
IGBT	Insulated Gate Bipolar Transistor
IMO	International Maritime Organization
IN	Ice numeral
MARPOL	International Convention for the Prevention of Pollution from Ships
MoES	Ministry of Earth Science
MT	Metric Ton
MW	Megawatts
MWT	Megawatts-Thermal
NCPOR	National Centre for Polar and Ocean Research
NIOT	National Institute of Ocean Technology
NSR	Northern Sea Route
PC	Polar code
POLARIS	Operational Limitations Assessment Risk Indexing System
PRSV	Polar Research and Supply Vessels
PWOM	Polar Water Operational Manual
RIO	Risk Index Outcome
RVs	Risk Values
SAR	Search & Rescue
SOLAS	Safety of Life at Sea

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TECHNICAL NOTES

A Study on Shipowners' Protections and Liabilities in Maritime Accidents

Shantanu Paul

The study is an academic exercise to review issues relevant to shipowners in a ship accident case. Discussions are not intended to cover all aspects of the accident and are limited to shipowners' protections concerning marine insurance and liabilities under IMO conventions.

Maritime Accident (hypothetical case): A crude oil tanker of 29500 GT, classed under an IACS classification society, suffered hull damage following a tank explosion and sank after a few days while undergoing salvage operations in the territorial sea of a coastal state.

(a) Study of ship-owner's protections with respect to marine insurance: -

1. As the ship sank, it was a case of Total Loss (TL). It may be a case of Actual Total Loss (ATL) when the ship is destroyed completely by sinking totally, or a case of Constructive Total Loss (CTL) by sinking partially in reasonably shallow depth in the territorial sea. CTL is considered when a property is damaged to a significant extent and the cost of repairing it to its pre-loss condition exceeds the property's insured value.

   The accident was caused by an explosion, which is one of the common perils covered under Hull and Machinery (H&M) policy. **Hence, the H&M insurer will pay the policyholder (ship-owner) the insured value of the ship, agreed value or market value, as applicable, provided the ship-owner has not breached any warranties of the policy, including seaworthiness** i.e., he has exercised due diligence at the beginning of the voyage to make the ship seaworthy, including fire and safety measures that might have caused the explosion and resulted in the sinking after her hull damage and apparently created oil pollution. Warranties, if breached, give a defense to the insurer, regardless of the existence of a causal link between the breach and loss.

2. In case of payment to the ship-owner by the H&M insurer for the TL amount (ATL or CTL), the hull insurers will have the right to assume title to the wreck and the owner is required to abandon it. If it is an Actual Total Loss (ATL), no notice of abandonment is required as per the Marine Insurance Act 1906. However, it is in the territorial sea, the water depth is not unreasonable, and with today's technology, the ship may be salvageable. Hence, shipowners, as a matter of routine, give notice of abandonment because they don't know whether it qualifies as an ATL or a CTL (Constructive Total Loss).

   However, hull insurers would normally forgo their right due to liabilities attached i.e., wreck removal and possibilities of pollution due to oil trapped in tanks. Limitation of liabilities under the IMO conventions is for ship-owners and extended to insurers also,

> *The accident was caused by an explosion, which is one of the common perils covered under Hull and Machinery (H&M) policy*

but H&M insurers do not have insurance like P&I (Protection & Indemnity), to provide indemnity for those liabilities. Hence, all liabilities will remain with the registered ship-owner or shipping company.

An unsuccessful salvage attempt may require wreck removal. If the coastal state has not extended the IMO wreck removal convention to apply in their territorial sea, then national laws will apply. **The IMO Wreck Removal Convention (WRC) 2007, also commonly referred to as the Nairobi Convention, is for wrecks located outside the territorial seas of the respective signatory states and within the Exclusive Economic Zone (EEZ), but also enables contracting states to declare, when adopting the convention, that they extend its application to the territorial sea.** However, this is not done by all parties (coastal states), considering their capability to apply national law, which is much more than the conventional limit, and removal of wreck is necessary only when it is a "hazard", e.g., navigational, as wrecks at around 500 metres depth may need monitoring only. The WRC does not provide for any specific right to limit; it provides that the registered owners are entitled to exercise whatever limitation rights they may have under general limitation conventions, e.g., Limitation of Liability for Maritime Claims Convention (LLMC) 1976 or any subsequent amendments. However, when states ratified LLMC, they could make a reservation against LLMC applying to wreck removal. Accordingly, Singapore, the United Kingdom, Germany and a few others have notified IMO of a reservation of the right to legislate for unlimited liability in respect of wreck removal. In such states, ship owners will have no right to limit for liabilities arising under the WRC. Nevertheless, wrecks in the territorial sea are likely to pose some hazard and the coastal state will put the liability of wreck removal on the ship-owner, the cost of which will be covered under the P&I insurance, as historically done prior to WRC.

(b) Study of ship-owner's liabilities under related IMO conventions: -

3. Crude oil tankers need to have certificates for the Civil Liability Convention (CLC) and Bunker Convention (BC), as CLC covers tankers carrying persistent oil cargo and the bunkers of such a tanker, but for bunker oil from an unladen tanker, the BC may apply. An unladen tanker which had carried a cargo of persistent oil would fall outside the definition of "ship" under CLC, if it had no residues of such carriage on board, such as in the positioning voyage after dry-docking, when the vessel is clean and gas free etc. Therefore, ship-owner's liabilities under the CLC, BC and WRC will continue as discussed above. All three impose "strict liability" on ship-owners; hence, a certificate of insurance issued by the Flag State based on the guarantees of ship-owners' P&I Club under the respective Blue Card for all three conventions needs to be produced to the coastal State for compensation. Moreover, if payment of compensation is required to be made under the Fund Convention (FC), then, over and above the CLC amount, then ship-owners' P&I Club needs to indemnify the Fund by up to 20 million Special Drawing Rights (SDR). The CLC amount increased to 20 million SDR under the voluntary agreement of the "Small Tanker Oil Pollution Indemnification Agreement" (STOPIA) that applies to small tankers of less than 29,548 GT covered under a P&I Club that is a member of the International Group (IG) of P&I Clubs. The combined limit under CLC and FC is 203 million SDR (Fig-1). STOPIA rules are "*lex specialis*", which takes precedence over the general law, CLC in this case. STOPIA is to ensure that the costs of responding to spills of persistent oil are more equitably borne by ship-owners and the receivers of oil, as the Fund is financed by contributions levied on companies or other entities in a Fund Member State that receives an annual quantity of more than 150,000 tons of 'contributing oil' following carriage by sea. The oil may be imported from abroad, carried from another port in the same State or transported by ship from an offshore production rig. The Supplementary Fund and TOPIA (Tanker Oil Pollution Indemnification Agreement) are not discussed as not related to the subject case.

As the ship sank after a few days, there was possibly a need for the rescue of seafarers on-board the ship, hence the application of the Search and Rescue (SAR) Convention by the coastal State. Under the SAR Convention, there is no mention of any charge for such a service and the coastal State would normally bear

> *Hence, shipowners, as a matter of routine, give notice of abandonment because they don't know whether it qualifies as an ATL or a CTL (Constructive Total Loss)*

> *Under the SAR Convention, there is no mention of any charge for such a service and the coastal State would normally bear the cost, but some coastal states, especially those who are not party to the SAR convention, may charge the ship-owner, as per their national law, for the assistance given to a ship in distress or rescue of crew*

the cost, but some coastal states, especially those who are not party to the SAR convention, may charge the ship-owner, as per their national law, for the assistance given to a ship in distress or rescue of crew. Also, the repatriation of seafarers after being rescued and brought ashore is on the ship-owners' account and secured by insurance, often P&I, as required under the Maritime Labour Convention, 2006 of ILO. However, deployment of resources by the coastal state for emergency response, such as tugs with towing and fire-fighting capabilities, is also charged to the ship-owner, often as per the tariff of the coastal state, as a "maritime assistance service" by the coastal state is distinct from a SAR service.

4. The ship-owner engaged a salvage company, possibly under Lloyd's Open Form (LOF), which is a standard contract form for marine salvage operations based on the traditional principle of "No Cure - No Pay". Hence, "Special Compensation" was introduced under Article-14 of the IMO Salvage Convention (SC). Article 14 is intended to encourage salvors to assist ships that threaten environmental damage (pollution) in the territorial sea. Hence, if the salvage company has reduced environmental damage, possibly by transferring some crude oil cargo in a few days' time, without any involvement in the subsequent hull damage to the vessel due to a faulty salvage strategy, then Special Compensation may be paid, which is normally 30% above the salver's expenses and paid by the ship-owner's P&I Club. No bank guarantee or insurance is required for Article 14 claims, but it is under lien status in many jurisdictions. Lien is a special category of maritime claims, hence, if not paid, on other ships of the same owner (sister ship), arrest may be ordered by the coastal state's court. Liens are mostly regulated by national law, rather than international convention, because most countries have not wanted to give up their own ideas as to what claims are protected by lien. **However, under the "flag of convenience" (FOC), ships are almost invariably registered with single-purpose companies (one company per ship), and consequently, the ships always have different owners.** In such a case, sister-ship arrest is not feasible, and consequently, Article 14 payment becomes uncertain.

> *To avoid all such problems and uncertainties of payment to salvor, the salvage industry and the International Group (IG) of P&I Clubs agreed on the Special Compensation P&I Clause (SCOPIC), which is an alternate payment system based on a tariff of daily rates for equipment and personnel engaged*

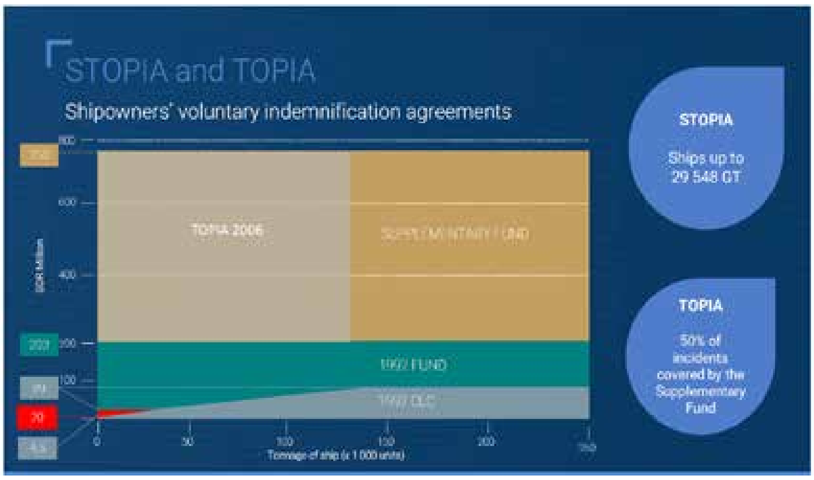

Figure. 1

5. Nevertheless, the Article 14 application proved to be very difficult, and it did not really encourage salvors as there was no real assurance that Special Compensation would be awarded. Also, equipment and personnel rates should not include an element of profit. Hence, disputes about the cost or payment amount have led to long and costly litigation. Also, if the ship-owner can prove that the salvor was negligent or unprofessional, then the salvor may be deprived of the whole or part of special compensation or even incur excessive liability, hence protected by the IMO convention of LLMC. Nevertheless, salvor cannot be made liable for pollution due to the provision of "responder immunity clause", inbuilt in the CLC and majority of coastal states, while incorporating BC in their national law have considered it for the protection of persons responding to BC incidents. To avoid all such problems and uncertainties of payment to salvor, the salvage industry and the International Group (IG) of P&I Clubs agreed on the Special Compensation P&I Clause (SCOPIC), which is an alternate payment system based on a tariff of daily rates for equipment and personnel engaged. SCOPIC is an option in LOF and replaces Article 14 if invoked. The subject ship sank after a few days due to structural damage following a tank explosion and during the salvage operation. Hence, salver's performance may not be beyond controversy. As SCOPIC can be invoked by the salvor at any time, hence, in all probability, it was done by the salvage company. Then the ship-owner is obliged to provide security within two days for a bank guarantee or Letter of Undertaking from the P&I Club of US$ 3 million. Ship-owner's strict liabilities under IMO conventions i.e., CLC, BC, and WRC, have to be covered by compulsory insurance, usually provided by the owner's P&I club and, differently from normal

legal principles, claims may be made directly against the insurer. Other P&I payments, however, are subject to the "pay to be paid" principle, i.e., the shipowner has to pay first and the club will indemnify it. If the ship-owner becomes bankrupt, then payments are uncertain!

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Notes:

1. The discussions are based on Author's personal views.
2. For better understanding, websites of IMO, ITOPF, DGS, IACS Classification Societies, P&I Clubs may be referred to.
3. In addition, a few available Theses on respective areas may be referred to.
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TECHNICAL NOTES

IMO STRATEGY FOR UPTAKE OF DUAL FUEL VESSELS & E-FUELS

Sanjay Relan

Abstract

The International Maritime Organization (IMO) has introduced a Net Zero Framework targeting a progressive reduction in greenhouse gas (GHG) fuel intensity for international shipping, aiming for net zero emissions by 2050. This framework mandates annual GHG intensity reductions from a 2008 baseline and enforces penalties for non-compliance, while incentivising the adoption of zero to near-zero (ZNZ) fuels and dual-fuel vessels through a Net Zero Fund.

Brief Notes:

- **IMO Net Zero Framework targets:** The framework sets a baseline GHG Fuel Intensity (GFI) of 93.3 g CO2e/MJ from 2008, with annual reduction targets leading to a 30% reduction by 2035 for the base target and 43% for direct compliance, aiming for net zero by 2050. Targets beyond 2035 remain unspecified.
- **Penalty structure for non-compliance:** Ships failing to meet the base target incur a penalty of US$380 per metric ton of CO2e, while missing direct compliance targets results in a US$100 per metric ton penalty. Penalties are calculated based on the gap between actual fuel GHG intensity and IMO targets multiplied by fuel consumption and calorific value.
- **Financial impact on fossil fuel users:** Penalties can double fuel costs by 2035, raising costs from US$500 to over US$1000 per metric ton of fossil fuel burned under a 'pay to pollute' strategy, significantly increasing operational expenses for shipowners using fossil fuels.
- **Revenue generation for IMO Net Zero Fund:** Penalties are projected to generate between US$12 billion and US$60 billion annually, assuming 250 million metric tons of fossil fuel consumption and 50% compliance with sustainable biofuels. The fund supports incentives for early adoption of ZNZ fuels and dual-fuel vessels.
- **Incentives for ZNZ fuels:** Fuels with GHG intensity below 19 g CO2e/MJ until 2035 (and below 14 g CO2e/MJ thereafter), including bio-methanol, e-ammonia, and e-methanol, qualify for reward units that offset their higher costs, which can be up to four times that of fossil fuels.
- **Support for dual-fuel vessels:** Dual-fuel capable vessels, which have 20-25% higher capital expenditure, could receive surplus and reward units valued at approximately US$300 each, helping to mitigate the additional investment cost and encourage transition to ZNZ fuels.
- **Economic analysis of e-methanol use:** Over eight years, a dual-fuel bulk carrier using e-methanol can realise net benefits of approximately US$6.7 million from selling surplus units and obtaining reward units, offsetting the higher fuel and vessel costs compared to fossil fuel use.
- **Upcoming adoption challenges:** The framework requires a two-thirds majority vote at the October 2025 MARPOL session to be implemented. While the April 2025 vote showed a majority in favour, opposition led by petrostates poses a significant challenge to adoption.

IMAGE SOURCE: ABS, MEPC83 BRIEF, PUBLISHED APRIL 2025

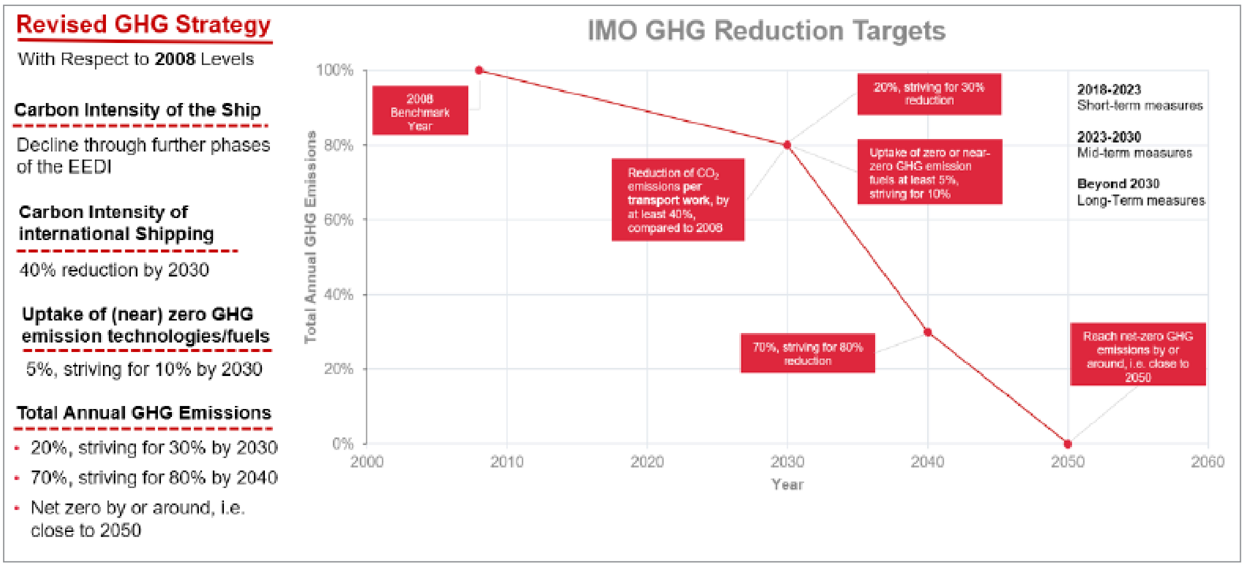

Figure 1 – IMO GHG Reduction Targets

INTRODUCTION

To reach Net Zero Greenhouse Gas (GHG) emissions by approximately 2050, the IMO MEPC 83, in April 2025, established the NET ZERO FRAMEWORK, mandating a progressive reduction in the GHG intensity of fuel on a Well-to-Wake (WtW) basis, starting from a GHG Fuel Intensity (GFI) baseline of 93.3 g CO2e/MJ (reflecting the 2008 average eGFI for international shipping).

The IMO has outlined the GHG reduction trajectory and remedies via penalties for non-compliance, contributing to an IMO Net Zero Fund, as follows:

1. **Base Target GFI Penalty**: Non-compliance with the base GHG Fuel Intensity (GFI) target incurs a higher penalty of US$380 per metric ton of CO2e through purchase of Remedial Units via IMO or Surplus Units from other ships.
2. **Direct Compliance Target GFI Penalty**: Non-compliance with the direct compliance GFI target incurs a lower penalty of US$100 per metric ton of CO2e. This cannot be obtained from other ships.
3. **Surplus Units/ Overcompliance Benefits**: Achieving overcompliance generates surplus units that can be

IMAGE SOURCE: ABS, MEPC83 BRIEF, PUBLISHED APRIL 2025

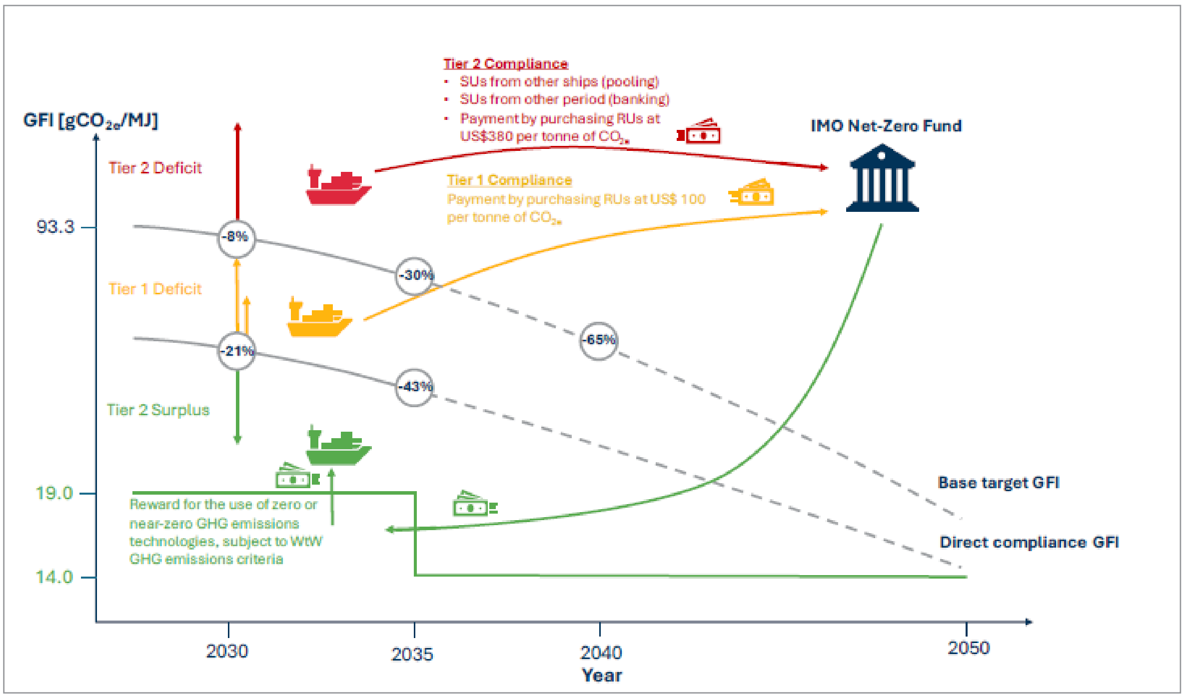

Figure 2 – Compliance Timelines

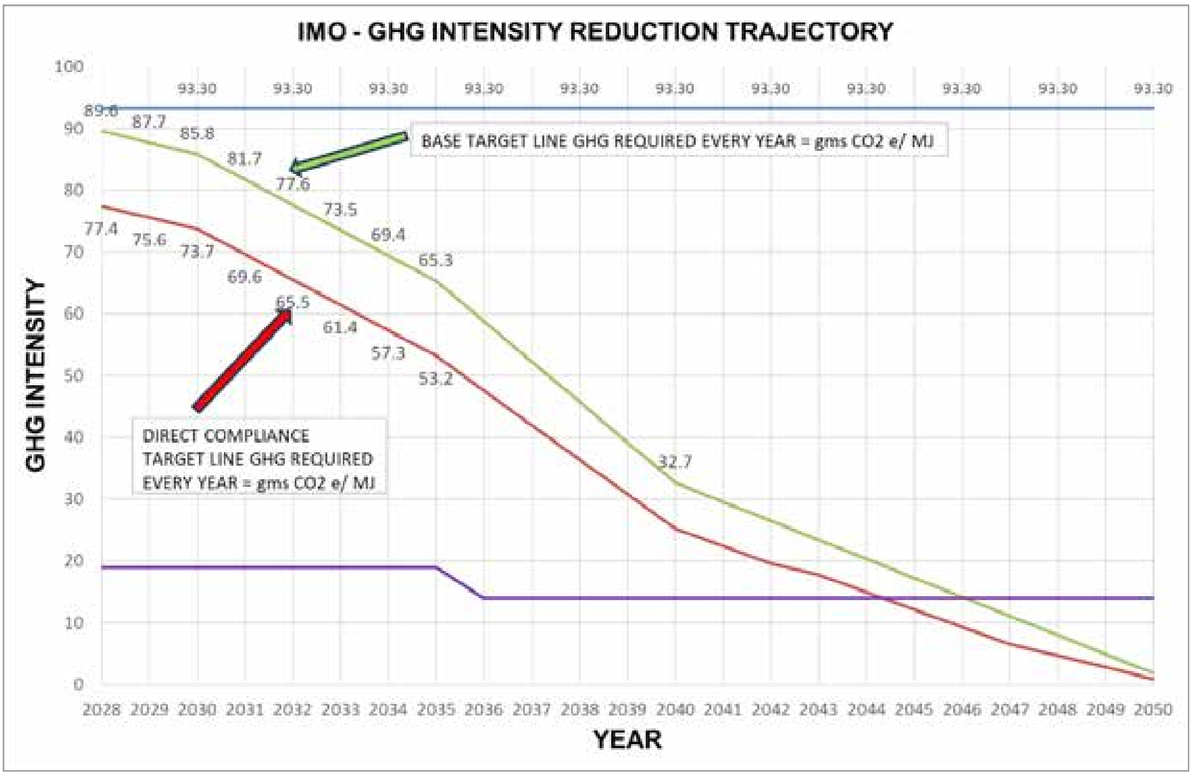

Figure 3 – IMO GHG intensity reduction trajectory for Base Target and Direct Compliance Target

sold, transferred, or banked for use within the next two years.

4. **Reward Units for ZNZ Fuels**: Use of Zero to Near-Zero (ZNZ) fuels with GHG intensity below 19 g CO2e/MJ (until 2035) or below 14 g CO2e/MJ (from 2036) qualifies for Reward Units. Eligible fuels would include bio-methanol, e-ammonia, and e-methanol. It is not yet known if biofuels would be included in this category.

PART 1 – HOW ARE THE GHG TARGETS & FORWARD CURVES DERIVED FROM THE % REDUCTION INFORMATION PROVIDED BY IMO

Blue Line: Represents the IMO GHG Fuel Intensity (GFI) baseline of 93.3 g CO2e/MJ, reflecting the average GFI of international shipping in 2008.

Green Line: Represents the Base Target Line, indicating the IMO GFI target intensity (g CO2e/MJ) for fuel used, reduced by a specific percentage annually. The IMO has not to provide targets (2036–2039 or > 2041)

Red Line: Represents the Direct Compliance Target Line, indicating the IMO GHG Fuel Intensity (GFI) target (g CO2e/MJ) for fuel used, reduced by a specific percentage annually. The IMO has not yet specified targets for 2036–2050.

.Year	Base line GHG (Co2e/ MJ) = Blue line	Base Target GHG reduction required in %	This translates to a GHG target intensity of (Co2e/ MJ) = Green line above
2028	93.3	4	93.3 x (1- 4.0/100) = 89.6 g Co2e/MJ
2029	93.3	6	93.3 x (1- 6.0/100) = 87.7 g Co2e/ MJ
2030	93.3	8	93.3 x (1- 8.0/100) = 85.8 g Co2e/ MJ
2031	93.3	12.4	93.3 x (1-12.4/100) = 81.7 gCo2e/ MJ
2032	93.3	16.8	93.3 x (1-16.8/100) = 77.6 gCo2e/ MJ
2033	93.3	21.2	93.3 x (1-21.2/100) = 73.5 gCO2e/ MJ
2034	93.3	25.6	93.3 x (1-25.6/100) = 69.4 gCo2e/ MJ
2035	93.3	30	93.3 x (1-30.0 /100) = 65.3 gCo2e/ MJ
2040	93.3	65	93.3 x (1-65.0 /100) = 32.7 g CO2e/ MJ

Table 1 – IMO GHG Base target intensity reduction trajectory calculation

Year	Base line GHG intensity (Co2e/ MJ) = Red line	Direct compliance Target GHG intensity required in %	This translates to a GHG target intensity of (Co2e/ MJ) = Red line above
2028	93.3	-17%	93.3 x (1- 17.0/100) = 77.4 g Co2e/MJ
2029	93.3	-19%	93.3 x (1- 19.0/100) = 75.6 g Co2e/ MJ
2030	93.3	-21%	93.3 x (1- 21.0/100) = 73.7 g Co2e/ MJ
2031	93.3	-25.4%	93.3 x (1-25.4/100) = 69.6 g Co2e/ MJ
2032	93.3	-29.8%	93.3 x (1-29.8/100) = 65.5 gCo2e/ MJ
2033	93.3	-34.2%	93.3 x (1-34.2/100) = 61.4 gCO2e/ MJ
2034	93.3	-38.6%	93.3 x (1-38.6/100) = 57.3 gCo2e/ MJ
2035	93.3	-43%	93.3 x (1-43.0 /100) = 53.2 gCo2e/ MJ

Table 2 – IMO GHG intensity reduction trajectory calculation

PART 2 - HOW IS THE PENALTY AMOUNT DERIVED FOR CONSUMING 1 MT OF FOSSIL FUEL FOR A ' PAY TO POLLUTE' SCENARIO

1.Calculating Base penalty - IMO has provided a US$ 380/ MT Co2e Base Penalty or cost of a Remedial Unit

For a vessel burning 1 MT Fossil Fuel, the penalty is calculated as the difference in GHG intensity (Target-base line) X Calorific Value of the fuel x MT of fuel consumed

Year	GHG LFO	Base Target GHG	Deficit	Calorific Value of Fuel	Base Penalty	Base Penalty/ MT Fossil Fuel burnt (Red Line above)
	(Co2e/ MJ)		gCo2e/MJ	MJ/MT	US$/ MT Co2e	US$
2028	95.5	89.6	95.5-89.6 = 5.9	0.0402	380	5.9 x 0.0402 x 380 = 91
2029	95.5	87.7	95.5-87.7 = 7.8	0.0402	380	7.8 x 0.0402 x 380 = 119
2030	95.5	85.8	95.5 – 85.8 = 9.7	0.0402	380	9.7 x 0.0402 x 380 = 148
2031	95.5	81.7	95.5 – 81.7 – 13.8	0.0402	380	13.8 x 0.0402 x 380 = 210
2032	95.5	77.6	95.5 – 77.6 = 17.9	0.0402	380	17.9 x 0.0402 x 380 = 273
2033	95.5	73.5	95.5 – 73.5 = 22.0	0.0402	380	22.0 x 0.0402 x 380 = 336
2034	95.5	69.4	95.5 – 69.4 = 26.1	0.0402	380	26.1 x 0.0402 x 380 = 398
2035	95.5	65.3	95.5 – 65.3 = 30.2	0.0402	380	30.2 x 0.0402 x 380 = 461

Table 3 – IMO GHG Base Penalty trajectory calculation

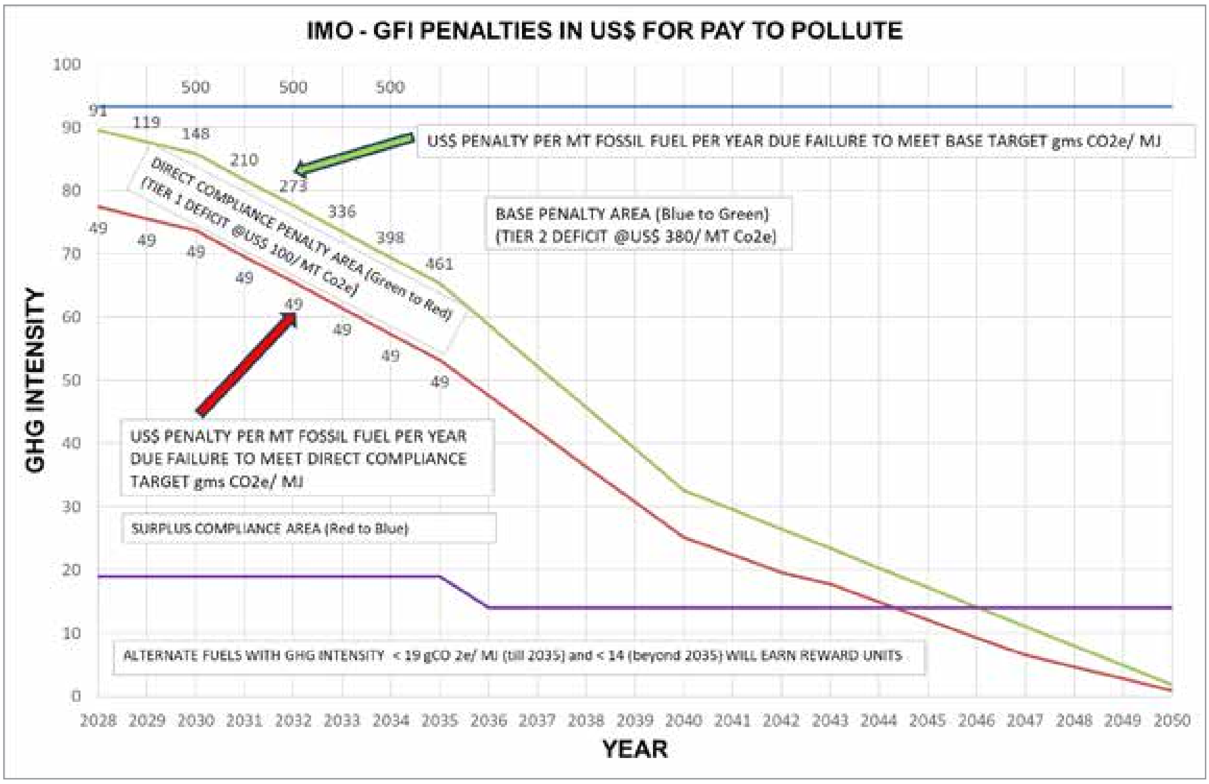

Figure 4 – IMO GHG – Penalty in US$ for Base Target and Direct Compliance Target

Now that we know the Base penalty per MT fossil fuel consumed, assuming annual fossil fuel consumption to be 250 million MT/year and 50% compliance by use of sustainable biofuels, the funds generated annually by the Base penalty or by IMO selling Remedial units

1. At the lowest in 2028 = 250 million MT fossil fuel/ year x 50% x US$ 91/ MT fossil fuel = US$ 11,375 million or US$ 11.4 billion
2. At the highest in 2035 = 250 million MT fossil fuel/ year x 50% x US$ 461/ MT fossil fuel = US$58 billion.

2. Calculating Direct Compliance penalty - IMO has provided a US$ 100/ MT Co2e Direct Compliance Penalty

For a vessel burning 1 MT Fossil Fuel, the penalty is calculated as the difference in GHG intensity (Base Line to Direct Compliance line) X Calorific Value of the fuel x MT of fuel consumed

Year	Base Target	Direct Compliance Target	Deficit	Calorific Value of Fuel	Base Penalty	Base Penalty/ MT Fossil Fuel burnt (Green Line above)
	Co2e/ MJ	Co2e/ MJ	gCo2e/MJ	MJ/MT	US$/ MT Co2e	US$
2028	89.6	77.4	89.6 - 77.4 = 12.2	0.0402	100	12.2 x 0.0402 x 100 = 49
2029	87.7	75.6	87.7 - 75.6 = 12.2	0.0402	100	12.2 x 0.0402 x 100 = 49
2030	85.8	73.7	85.8 - 73.7 = 12.2	0.0402	100	12.2 x 0.0402 x 100 = 49
2031	81.7	69.6	95.5 - 69.6 = 12.2	0.0402	100	12.2 x 0.0402 x 100 = 49
2032	77.6	65.5	95.5 - 65.5 = 12.2	0.0402	100	12.2 x 0.0402 x 100 = 49
2033	73.5	61.4	95.5 – 61.4 = 12.2	0.0402	100	12.2 x 0.0402 x 100 = 49
2034	69.4	57.3	95.5 – 57.3 = 12.2	0.0402	100	12.2 x 0.0402 x 100 = 49
2035	65.3	53.2	95.5 – 53.3 = 12.2	0.0402	100	12.2 x 0.0402 x 100 = 49

Table 4 – IMO GHG Direct Compliance Penalty trajectory calculation

The Direct Compliance Penalty is a fixed US$49 per metric ton of fossil fuel burned, a modest amount sufficient to offset non-compliance with a significant GHG reduction of 12.2 g CO2e/MJ. This penalty is structured to generate a consistent revenue stream for the IMO Net Zero Fund, calculated as 250 million metric tons of fossil fuel per year × US$49 per metric ton, yielding approximately US$12 billion annually.

Funds from the IMO Net Zero Fund are used to incentivise early adopters by providing reward units to offset the higher costs of dual-fuel vessels (20-25% more expensive) and e-fuels (up to four times the cost of fossil fuels for equivalent energy).

3. Calculating the sum of Base penalty + Direct compliance penalty per MT of fossil fuel burnt for a shipowner who does not have access to sustainable biofuels and decides to continue using fossil fuels

Year	Base Penalty	Direct Compliance Penalty	TRANSLATES TO	Base Penalty/ MT Fossil Fuel burnt	Direct Compliance Penalty/ MT Fossil Fuel burnt	TOTAL IMO GFI PENALTY/ MT Fossil fuel burnt
	US$ / MT Co2e	US$ / MT Co2e		US$	US$	US$
2028	380	100		91	49	91+49= 140
2029	380	100		119	49	119+49 = 168
2030	380	100		148	49	148+49 = 197
2031	380	100		210	49	210+49 = 259
2032	380	100		273	49	273+49 = 322
2033	380	100		336	49	336+49= 385
2034	380	100		398	49	398+49 = 447
2035	380	100		461	49	461+49 = 510

Table 5 – IMO GHG Base and Direct Compliance Penalty trajectory calculation

FINAL – IF FOSSIL FO COST = US$ 500/MT, THE NEW FUEL COST WILL BE = FUEL COST + IMO GFI PENALTY IF SHIPOWNER IS OPERATING ON A ‘ PAY TO POLLUTE’ STRATEGY

Year	Fossil Fuel cost – US$ / MT	TOTAL IMO GFI PENALTY/ MT Fossil Fuel burnt	NEW FUEL COST TO OWNER – US$/ MT
2028	500	140	500+140 = 640
2029	500	168	500+168 = 668
2030	500	197	500+197 = 697
2031	500	259	500+259 = 759
2032	500	322	500+322 = 822
2033	500	385	500+385 = 885
2034	500	447	500+447 = 947
2035	500	510	500+510 = 1010

Table 6 – New fuel per MT costs on a ‘Pay to Pollute” scenario calculation

For a shipowner adopting a “Pay to Pollute” strategy, the IMO GHG Fuel Intensity (GFI) penalty will raise fuel costs from US$500 to US$1010 over eight years, assuming the IMO maintains the Tier 2 penalty at US$380 per metric ton of CO2e and the Tier 1 penalty at US$100 per metric ton of CO2e. However, the IMO may adjust these penalty rates upward starting in 2031 and at defined intervals thereafter.

For a bulk carrier burning 5,000 metric tons of fossil fuel annually, this would result in the vessel annual fuel bill doubling within eight years, as outlined below.

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Year	Original Fuel cost	GFI Penalty per vessel (US$)	GFS Penalty per vessel (US$)	Total GFI penalty (US$)	New Fuel + GFI penalty cost
2028	2,500,000	453,086	243,793	696,879	3,196,879
2029	2,500,000	595,611	243,793	839,404	3,339,404
2030	2,500,000	738,136	243,793	981,929	3,481,929
2031	2,500,000	1,051,691	243,793	1,295,484	3,795,484
2032	2,500,000	1,365,247	243,793	1,609,040	4,109,040
2033	2,500,000	1,678,802	243,793	1,922,595	4,422,595
2034	2,500,000	1,992,357	243,793	2,236,150	4,736,150
2035	2,500,000	2,305,912	243,793	2,549,705	5,049,705

Table 7 – New annual fuel costs on a 'Pay to Pollute" scenario calculation

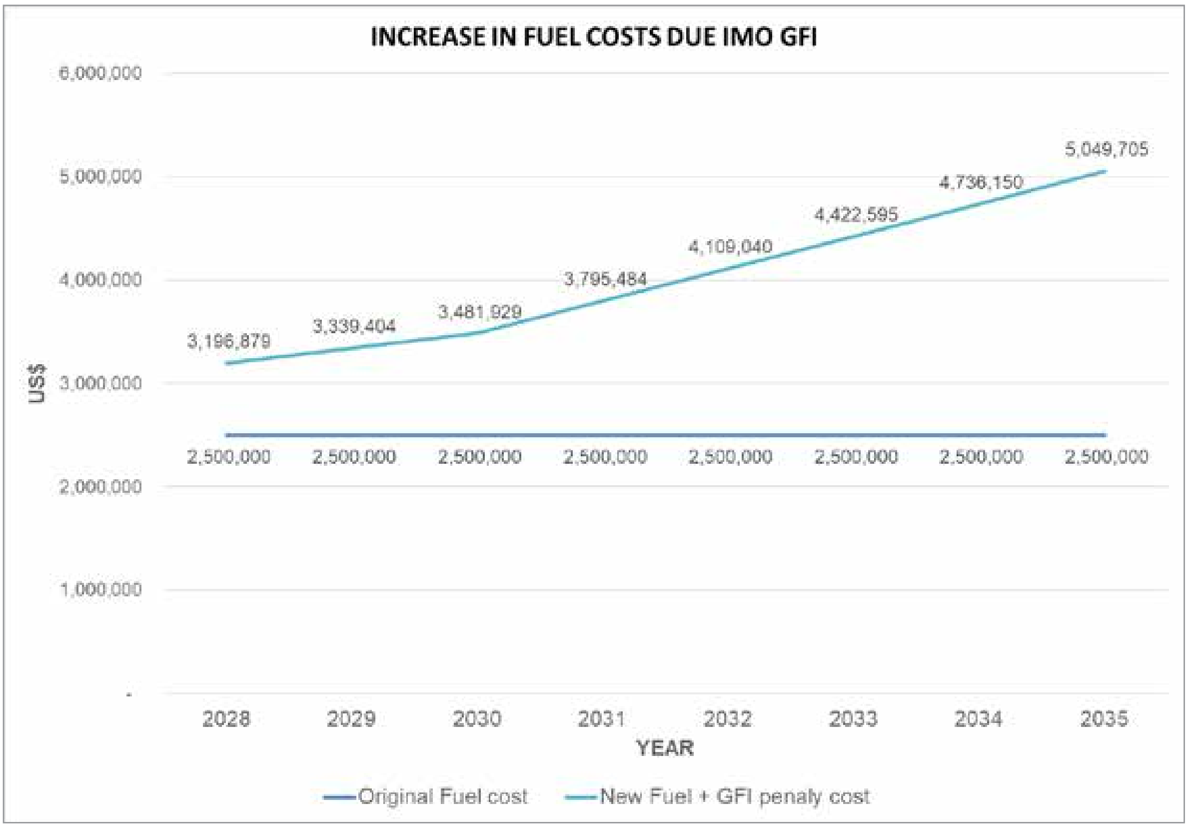

Figure 5 – Fuel costs increase 2028-2035 on a "Pay to Pollute" scenario

The illustration above shows the annual fuel bill of about US$ 2.5 million to double to US$ 5 million in 8 years for a vessel burning 5000 MT fossil fuel every year due to IMO-GFI rules.

Part 3: HOW DOES THE IMO GFI INCENTIVISE

a) **Uptake of Zero to Near-Zero (ZNZ) Alternative Fuels**: The IMO GFI framework encourages the adoption of ZNZ fuels (e.g., bio-methanol, e-ammonia, e-methanol), which can cost up to four times more than fossil fuels for equivalent energy, by offering Reward Units for fuels with GHG intensity below 19 g CO2e/MJ (until 2035) and below 14 g CO2e/MJ (from 2036). These financial incentives, funded through the IMO Net Zero Fund, help offset the higher costs of ZNZ fuels.

b) **Ordering of Dual-Fuel Capable Vessels**: The IMO GFI promotes the construction of dual-fuel vessels, which are 20-25% more expensive than standard vessels, by providing Surplus Units and Reward Units. These units, valued at an assumed US$300 each, will substantially reduce the financial burden of investing in dual-fuel technology and encouraging shipowners to transition to vessels capable of using ZNZ fuels.

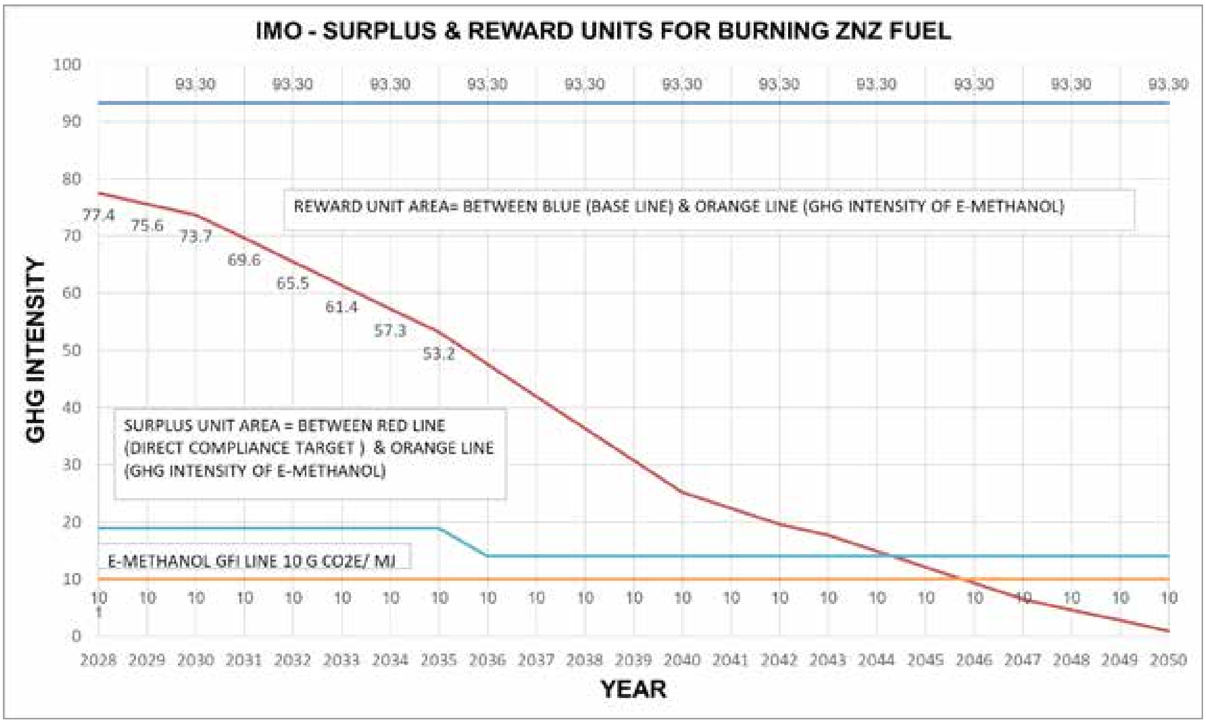

Figure 6 – Calculating Surplus and Reward units

SURPLUS UNIT BENEFIT

Note 1: Approximately 2.02 times more methanol is required to deliver the same energy as fuel oil (FO), as the calorific value of FO is 40.2 GJ/MT, while methanol is 19.9 GJ/MT (40.200 ÷ 19.900 ≈ 2.02).

Note 2: The cost of e-methanol is assumed to be US$1,000/MT at the pump (potentially secured through long-term offtake agreements), equating to an effective cost of US$2,020 for the shipowner to achieve the same energy content as FO.

Note 3: The GHG intensity of e-methanol is estimated at 10 g CO2e/MJ, with a potential range of 2.5 to 12.5 g CO2e/MJ.

Case: The following scenario applies to a dual fuel vessel burning 5,000 MT of FO annually (at US$ 500/ MT) or 10,100 MT e-Methanol (at US$ 1000/ MT).

Year	Equivalent E-Methanol (MT)	GHG intensity of E Methanol g Co2e/ MJ	Surplus Units generated = Direct compliance target line to GHG intensity of E-Methanol	Calorific value of E-Methanol (19,900 GJ/ MT)	Co2e (MT) surplus generated	Surplus unit in US$/ Unit (say US$ 300/ MT Co2e)	Additional Cost of E-Methanol
2028	= 5000 x 40,200/ 19,900 = 10,100	10	77.4-10 = 67.4	19,900	= 67.4 x 10,100 x 19,900/10^6 = 13,546	=13,546 x 300 = 4,083,800	= US$ 1,000/ MT x 10,100 MT – US$ 500/ MT x 5,000 MT = 7,600,000
2029	10,100	10	75.6-10 = 65.6	19,900	13,184	3,955,200	7,600,000
2030	10,100	10	73.7-10 = 63.7	19,900	12,803	3,840,900	7,600,000
2031	10,100	10	69.6 –10 = 59.6	19,900	11,985	3,595,500	7,600,000
2032	10,100	10	65.5-10 = 55.5	19,900	11,154	3,346,200	7,600,000
2033	10,100	10	61.4-10 = 51.4	19,900	10,336	3,100,800	7,600,000
2034	10,100	10	57.3-10 = 47.3	19,900	9,506	2,851,800	7,600,000
2035	10,100	10	53.2-10 = 43.2	19,900	8,682	2,604,600	7,600,000
					Total in US$	**27,378,800**	**60,800,000**

Table 8 – Revenue generated by selling Surplus units calculation at US$ 300/ MT Co2e

Benefit of Surplus Units: Over eight years, surplus units valued at US$300 per unit yield a benefit of US$27.378 million. This reduces the additional cost of e-methanol from US$60.8 million to US$33.421 million (US$60,800,000 – US$27,378,000).

REWARD UNITS BENEFIT

Note 1: The IMO has not yet finalised the methodology for calculating reward units.

Note 2: The actual cost of reward units in US$ will be confirmed in March 2027; a value of US$300 per unit is assumed for now. The Reward unit will not remain fixed but will change over time.

Benefit of Reward Units: Over eight years, reward units valued at US$300 per unit provides a benefit of US$40.18 million.

Year	Equivalent E-Methanol (MT)	GHG intensity of E Methanol gCo2e/ MJ	Surplus Units generated = Direct compliance target line to GHG intensity of E-Methanol	Calorific value of E-Methanol (19,900 MJ/ MT)	Co2e (MT) surplus generated	Reward unit in US$/ Unit (say US$ 300/ MT Co2e)
2028	= 5000 x 40,200/ 19,900 = 10,100	10	93.3-10 = 83.3	19,900	= 83.3 x 10,100 x 19,900/10^6 = 16,742	=16,742 x 300 = 5,022,600
2029	10,100	10	83.3	19,900	16,742	5,022,600
2030	10,100	10	83.3	19,900	16,742	5,022,600
2031	10,100	10	83.3	19,900	16,742	5,022,600
2032	10,100	10	83.3	19,900	16,742	5,022,600
2033	10,100	10	83.3	19,900	16,742	5,022,600
2034	10,100	10	83.3	19,900	16,742	5,022,600
2035	10,100	10	83.3	19,900	16,742	5,022,600
					Total in US$	**40,180,800**

Table 9 – Revenue generated by IMO reward units at US$ 300/ MT Co2e

CONCLUSION

	US$		US$	US$
SURPLUS BENEFIT	27,378,800	ADDITIONAL COST OF E-METHANOL	60,800,000	
REWARD UNIT BENEFIT	40,180,800			
TOTAL BENEFIT = A	67,559,600	TOTAL EXTRA OUTGO = B	60,800,000	NET BENEFIT 6,759,000

Table 10 – Net benefit of Surplus units and Reward calculation

Final Result of Operating a Dual-Fuel Vessel on e-methanol (2028–2035): The net positive due to selling surplus units to other vessels and obtaining reward units from IMO is approximately US$6.759 million (or US$6.7 million), roughly equivalent to the cost difference between a standard 64K DWT vessel and a dual-fuel methanol vessel.

Note 1: The adoption of the IMO GHG Fuel Intensity (GFI) framework requires a two-thirds majority vote from the 108 MARPOL signatories at the extraordinary session (MEPC/ES2) scheduled for October 14–17, 2025.

At the MEPC 83 meeting in April 2025, the vote was 63 in favour, 19 against, and 24 abstentions. The ES2 session may allow only a "yes" or "no" votes, with no abstentions permitted. There is a significant opposition, led by petrostates, aiming to derail the IMO GFI initiative to preventing the required 2/3rd yes votes.

Acknowledgements

Figure 1 – IMO GHG reduction targets - Source: ABS, MEPC83 Brief, published April 2025

Figure 2 – IMO GFI overall strategy - Source: ABS, MEPC83 Brief, published April 2025

About the Author

Sanjay Relan graduated from DMET, Kolkata in 1985. Presently he is attached to Pacific Basin Shipping (Hong Kong) Ltd., as 'General Manager-Decarbonisation & Environmental Compliance.' He is a Member of The Institute of Marine Engineers (India) (M-25004), Institute of Chartered Shipbroker (M-4810) and Technical Committees in Hong Kong-ABS. He is an Observer-Member of Class NK, DNV and LR.

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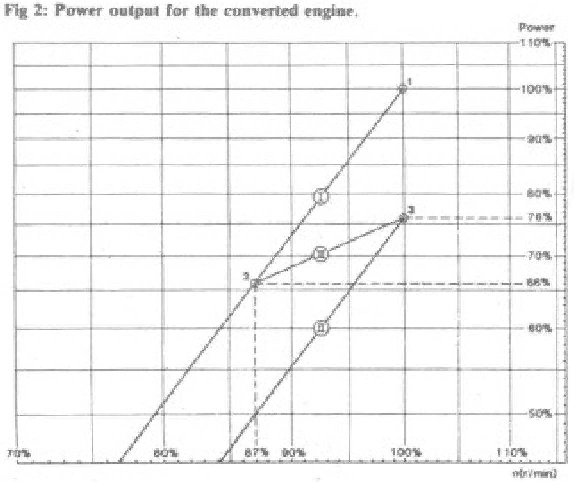
Going Astern into MER Archives...

The Editorial talks about superconducting machines. The merits and advantages of superconducting motors and generators are praised. In context, there are few research papers on superconducting machines for ship's propulsion applications. Are these machines in considerable use? If there is information available, it is welcome.

The first article is on engine conversion kits developed by MAN B&W. The kits make physical changes to the jacket, new piston and the works (Turbochargers, fuel cams etc.).

Fig 2: Power output for the converted engine.



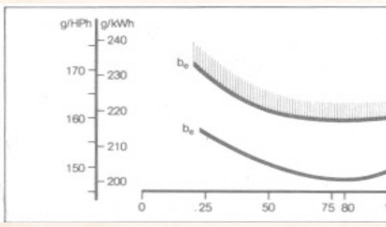
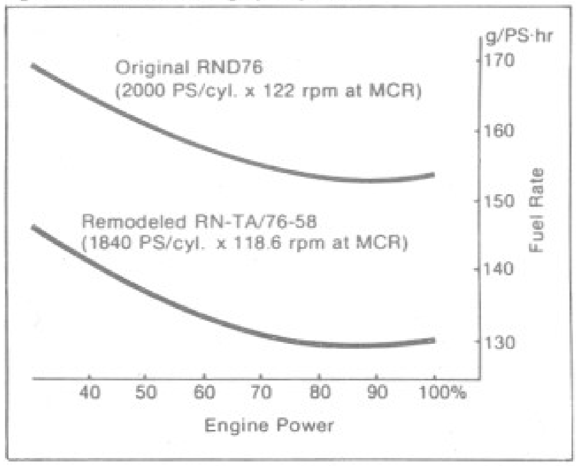


Fig 3: KZ70/120E specific fuel consumption before and after the conversion.

Fig 5: A fuel reduction of 24g/hph is possible.



The next article is on how CAD can help conversions and even ship repair. This is followed by a number of technical news items (saving/salvaging chemical cargoes, mooring and risers for floating platforms, self-unloading bulker, off shore vessel with multi-capability etc.). There is a Naval episode and also a call for supporting a Conference on training requirements for marine engineers.

The major takeaways are the four Transactions. All four of them are on auxiliary power generation (shaft generator, turbo alternator etc.). Paper #51 would be of good interest to the readers considering the analytics. Some extracts which could draw our readers to check out the Transactions...

Paper 49 Energy Saving in Ships' Power Supplies
Professor W. Hensel

Paper 50 Shaft-driven Generators for Marine Application
P. W. Murrell and L. Barclay

Paper 51 Production of Auxiliary Energy by the Main Engine
P. Schneider

Paper 52 Auxiliary Power Generation in Today's Ships
G. Mikkelsen

Discussion on Papers 49–52

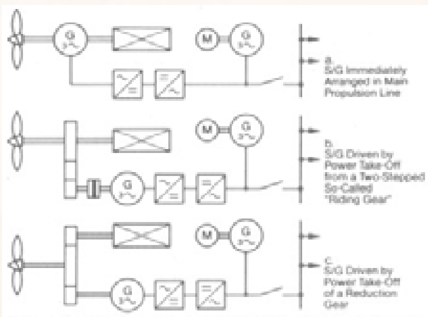


FIG. 2 Various possibilities of power-take-off for shaft alternator systems

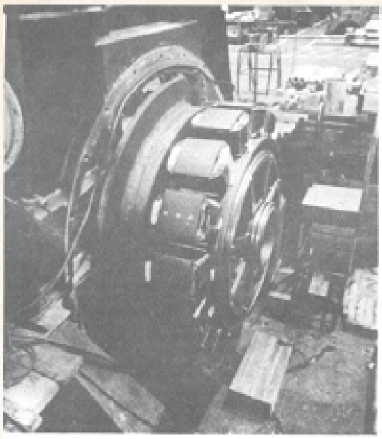


FIG. 3 Shaft-driven generator of disc-type construction without bearings, flanged on the non-drive end side of a two-stroke main engine

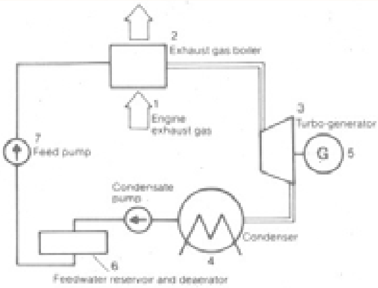


FIG. 8 Principle of exhaust gas turbo-generator

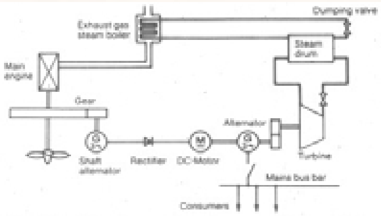
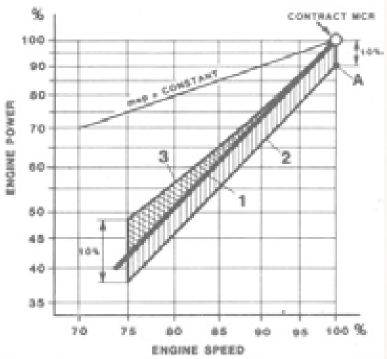


FIG. 10 Single-line diagram of supplementary drive supplied by shaft-driven generator



The generator, as an example, absorbs 10% of the engine contract MCR power. The propeller was designed as follows: Engine MCR-10% (generator) = 90% on the propeller (point A). The engine is not overloaded at 100% speed. If constant generator output is assumed (i.e. 10% of contract MCR) between 75 and 100% engine rev/min, the engine will have to follow curve 3 (i.e. the 90% propeller characteristic, curve 2 plus the generator, vertically shaded area). It appears that curve 3 is in the overload area, i.e. left of the 100% propeller law (curve 1). The overload increases at reduced speed. The oblique shading shows the overload zone.

FIG. 5 Example of an incorrect layout of propeller for an engine with FP-propeller and generator

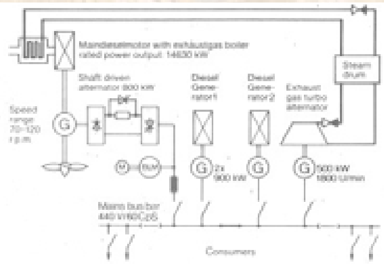
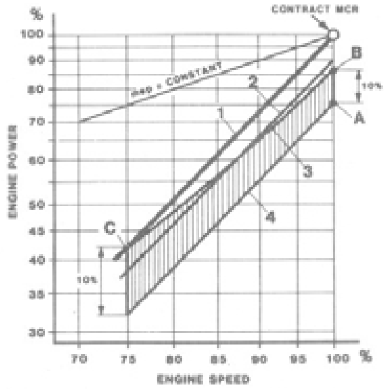


FIG. 11 Principle of power station designed for a 65 000 dwt product carrier



The generator is assumed to absorb 10% of contract MCR power, between 75 and 100% of contract MCR speed. The propeller now follows curve 4, the engine thus curve 3 (10% generator, vertically shaded area), selected in a manner that point C lies on the 100% propeller characteristic (curve 1). There is no overload, however; the maximum output on the propeller at contract MCR speed is thus only approx. 79% (point A), the engine max. output with generator (point B) thereby approx. 86% of contract MCR power. Curve 2 represents the 90% propeller characteristic.

FIG. 6 Same example as in Fig. 5 but 'corrected': the engine drives an FP-propeller and a generator

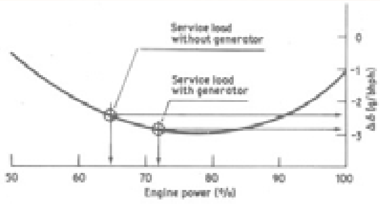


FIG. 8 Part-load curve for main engine, showing improved SFOC-figure caused by increased engine load from gnerator

Generator positioning	Engine room length*	Difference
Gear + generator in front of engine	25.2	3.5
Gear + generator on intermediate shaft	24.5	2.8
Integral generator intermediate shaft	25.2	3.5
Integral generator on fore end of engine	22.4	0.7
Epicyclic variable ratio gear on fore end of engine	23.8	2.1
Propulsion plant without generator	21.7	Basis

* Note: Total length of engine room—as long as this has already been kept at a minimum—i.e. the distance from aft bulkhead to engine should provide space for withdrawal of the propeller shaft.

FIG. 2 Comparison of required engine room length (for a 520 kW plant) depending on type of generator arrangement

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