PAPER

Ship Energy Efficiency Management Requires a *Total Solution* Approach

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ABSTRACT

Ship and fleet operating efficiencies are multifaceted and interdependent. As such, efficiency management must involve an integrated solution that extends across the entire operation of the fleet. No single metric can be used to indicate success or failure of improving overall efficiency. Rather, a comparative analysis of multiple metrics is required. Furthermore, to be viable, efficiency management must accommodate operating priorities, goals, and constraints. Technology to save fuel and reduce carbon footprint is only useful if critical mission objectives are also met. Most ships can reduce fuel consumption simply by slowing down, albeit at the expense of increased passage duration. Tactical objectives that require fast transit times or reliable just-in-time arrival may justify the associated increase in fuel consumption. Ship operators fulfilling those objectives must look for ways other than slow steaming to improve energy efficiency, including, for example, deployment optimization, smart voyage planning, and onboard energy management. Other key metrics associated with operating efficiency include health and safety of crew and cargo, ship life cycle costs, and unscheduled time in port. Through strategic application of multiple efficiency management tools, these costs may be maintained or reduced while supporting the operational objectives and constraints of ship, fleet, and operator. All of these aspects of ship and fleet operating efficiency may be quantitatively compared to previous baselines using objective benchmarking methodologies.
Keywords: ship efficiency SEEMP energy emissions

Overview

One would be hard-pressed to find anyone to argue against improving ship operating efficiency, given increasing pressures from today's socioeconomic and environmental realities. In ocean shipping, bunker fuel prices have more than quadrupled in the last decade, from about $170/metric ton in 2000. Indications of global climate change are driving new legislation aimed at reducing greenhouse gas (GHG) emissions, which are directly proportional to fuel consumption. In an effort to reduce pollution from other exhaust emissions, including sulfur, oxides of nitrogen, and particulate matter (soot), environmental control areas (ECA) are being established along coastlines of the United States and Europe.

What constitutes a net improvement in efficiency may not be so obvious. Fuel consumption rates may be easily reduced by slowing down, called "slow steaming," but voyage duration increases as a result, which may be unacceptable for time-critical shipments or cause the ship to be caught in a fast-moving storm. Many maritime technology companies focus on improving efficiency in a few specific areas without considering the impact on other operating requirements. For example, low-friction hull paint may offer improved fuel efficiency at sea, but its lower durability or resistance to marine growth may require more frequent and higher cost maintenance. Some weather routing service providers optimize ship routes based on running at fixed speeds and are unable to accommodate speed management such as slowing down to let a storm pass in front of the vessel or to postpone arrival at a port that is known to be congested at the planned arrival time.

Combining several different strategies without a clearly integrated plan makes it difficult to determine their individual effectiveness. Some procedures may only offer gains under certain operating conditions. Even worse, one procedure may be incompatible or interfere with another, resulting in a net decrease in efficiency or preventing the operator from being able to achieve its high-priority goals.

As one might conclude from this discussion, the definition of efficiency can vary with every application and every ship. One might say that it always boils down to cost, but this would reveal only part of the total picture. In military applications, for example, the top priority for efficiency may be to deliver critical materials, equipment, and personnel as quickly as possible to expeditionary forces in a battle zone, or to provide emergency relief to a disaster area. For shipping of perishable fruit, it may be to restrict ship motions to prevent bruising and to minimize transit times. For just-in-time manufacturing or retail sellers, efficiency may be gained by the shipped inventories arriving just in time—not too early and not too late. On-time arrival can also improve the efficiencies of port services, including connecting transportation services by road or rail. Of course, ship operating safety, which includes such human factors as crew comfort and health, is an essential component of operating efficiency.

In early 2009, the Oil Companies International Marine Forum (OCIMF) outlined these concerns in its publication, *Energy Efficiency and Fuel Management*, which describes a wide range of auditable, prioritized methodologies aimed at reducing CO_2 emissions by improving vessel and voyage efficiencies. Four main areas were addressed:

- minimizing energy waste,
- promoting energy efficiency awareness,
- implementing vessel and voyage strategies to minimize energy usage,
- promoting cooperation with charterers and others to facilitate energy efficient operations.

In its 2012 publication, *Guidance for the Development of a Ship Energy Efficiency Management Plan (SEEMP)*, the International Maritime Organization (IMO) joins OCIMF and others in recognizing that ship operating efficiency is a complex multifaceted problem. In an effort to advance standardized metrics for ship efficiency during design and operation, IMO introduced guidelines for calculating an Energy Efficiency Design Index (EEDI) and an Energy Efficiency Operating Indicator (EEOI) (IMO, 2009a, 2012a). Both of these indices compute the amount of CO_2 emitted per transport work (i.e., cargo load and distance traveled). The EEDI is calculated under predefined operating conditions through computer simulation during the design phase of new ships and is validated in sea trials. The EEOI is used to monitor the ongoing efficiency of ships already in operation. In July 2011, MARPOL Annex VI regulations were amended, adding a new Chapter 4 that mandates using EEDI for new ship designs and implementing SEEMPs for all existing ships. The regulations, which apply to all ships of 400 gross tons and above, entered into force on 1 January 2013.

On the military side, the U.S. Navy has had an interest for several decades in operating safety and efficiency at sea. Since the 1990s, in a program called Incentivized Energy Conservation (i-ENCON), ship crews have been trained in operational procedures and strategies to reduce energy consumption. The Navy's Fleet Weather Centers (FWC) in San Diego, CA, and Norfolk, VA, use a variety of tools, including computerized route optimization processes called Optimum Track Ship Routing (OTSR), to improve fleet fuel efficiency while mitigating weather-related navigation hazards. OTSR provides shore-based routers with recommendations for minimum transit time, while avoiding environmental conditions that could cause excessive motion, crew discomfort, cargo damage, and/or hull fatigue. It also provides routing guidance in the vicinity of strong ocean currents and restricted waters. More recently, with a goal to upgrade its aging OTSR tools, the U.S. Navy has started a program called Smart Voyage Planning Decision Aid (SVPDA). It is also testing onboard fuel efficiency monitoring tools, called Shipboard Energy Dashboard (SED), that gives sailors visual feedback on energy usage in real time.

Developing an Efficiency Management Strategy

The objectives in formulating an effective efficiency management strategy are first to identify all the various efficiency parameters that are applicable to a given activity and then to assign priorities, metrics, and goals to those parameters. It should be understood that because many of these factors are related and interdependent, improving the efficiency of one may reduce the efficiency of another. The objective, then, is to maximize the efficiencies of the highest priority parameters while mitigating loss of efficiency, if possible, in less critical areas. In the final analysis, if one is successful at maximizing the efficiencies in all critical areas, albeit at the expense of noncritical ones, this may be viewed as an overall successful outcome.

Table 1 outlines potential areas for improving ship energy efficiency as proposed by IMO in its SEEMP guidelines. IMO does not specify what metrics should be used for each parameter, although it does recommend using the EEOI calculation for overall SEEMP tracking.

As noted by IMO, the measures listed in its SEEMP guidelines are by no means exhaustive but are suggested for consideration for a given ship's SEEMP. Not all measures are applicable for a given ship, activity, or company. Also, some measures may have higher priorities in some applications than others. In our own experience with commercial shipping companies, other measurements of operating efficiency frequently come into play. Table 2 lists some of the more common ones.

More Bang for the Buck

In its publication, *Pathways to Low Carbon Shipping*, Det Norske Veritas (DNV) estimated the cost per ton of CO_2 for different measures aimed at reducing fuel consumption and associated GHG emissions (Alvik et al., 2009). This list is illuminating because it

TABLE 1

IMO recommended measures for SEEMP.

Efficiency Improvement Strategy	MEPC.1/Circ. 683 Section	Comments
Fuel-efficient operations		
Improved voyage planning	4.2-4.3	This category addresses ship route optimization in planning and execution using available software tools. IMO offers guidelines for voyage planning in its resolution A.893(21) (25 Nov. 1999).
Weather routing	4.4	Weather routing is a less comprehensive method of route planning that allows ships to avoid adverse weather conditions. Some solutions, however, may increase fuel consumption.
Just-in-time	4.5-4.6	This category is related to the concept of "Virtual Arrival," whereby, through communication with the destination port, a ship may slow down and delay arrival to avoid port congestion.
Speed optimization	4.7-4.10	Speed optimization includes "slow steaming," but also considers the optimal speed for a given ship design, as well as gradual increases in speed when leaving port. Speed reduction can result in adverse consequences, including increased vibration, soot, and fuel consumption.
Optimized shaft power	4.11	Optimizing shaft power includes running at constant RPM and usage of electronic engine management systems rather than human intervention.
Optimized ship handling		
Optimized trim	4.12	Most ships are designed to operate most efficiently with a designated amount of cargo at a certain speed. Adjusting fore/aft trim can have a significant effect on fuel consumption for a given draft and speed. Trim effects may be less noticeable in heavy seas.
Optimized ballast	4.13-4.15	Ballast is used to adjust trim, and has a significant effect on steering and autopilot response. A ship's Ballast Water Management Plan must also be observed.
Optimized propeller and inflow	4.16-4.17	Improvements to propeller design and water inflow to the propeller can increase propulsive efficiency.
Optimized use of rudder and autopilot	4.18-4.20	Misadjusted or poorly designed automated heading and steering control systems can cause excessive fuel consumption due to added resistance and distance sailed off track.
Maintenance and logistics		
Hull maintenance	4.21-4.24	Hull maintenance includes cleaning, repairing, and painting of the hull to reduce roughness, and propeller cleaning and polishing.
Propulsion system	4.25-4.27	Efficient operation of the propulsion system can be improved by using automated electronic engine control and monitoring systems. Preventive maintenance and timely repairs of malfunctions are essential for efficient operation.
Waste heat recovery	4.28-4.29	Products are now available that use thermal heat losses from power plants and exhaust gas to generate electricity and/or additional propulsion.
Improved fleet management	4.30-4.31	Effective fleet management offers one of the largest potential improvements in ship operating efficiency. (IMO and others estimate potential fuel savings as high as 50%.) The guiding objectives are to maximize paid passages and minimize ballast voyages for the period.

continued

TABLE 1

Continued.

Efficiency Improvement Strategy	MEPC.1/Circ. 683 Section	Comments
Improved cargo handling	4.32	Port efficiency is an important component of total ship efficiency. Delays at port due to congestion or inefficient usage of port facilities result in higher energy consumption as well as delayed departures. Efficient transfer to connecting transportation services (road, rail, etc.) should also be considered in the total efficiency calculation.
Energy management	4.33-4.34	This parameter addresses efficient use of shipboard electrical services. Thermal insulation and optimized locations for stowing refrigeration containers are factors in this measure.
Fuel type	4.35	Changing to some fuel types, for example, liquid natural gas (LNG), improves EEDI /EEOI because they produce lower carbon emissions per ton. Switching to higher viscosity bunker may reduce operating cost, although this does not improve EEOI. In either case, modifications to the power train may be necessary.
Other measures	4.36-4.39	This category includes new innovations in tracking fuel consumption, renewable energy resources, using shore power (cold ironing), and reducing hull friction (bubbles, etc.)

TABLE 2

Efficiency measures beyond IMO guidelines.

Description of Measure	Comments
Improved on-time arrival consistency	In some commercial shipping applications, on-time arrival is paramount, with late arrivals resulting in reprimands and costly penalties. In these situations, captains often "sprint and loiter" to assure meeting their ETA. This has a high cost in fuel consumption. Effective use of route optimization tools can increase on-time arrival reliability while reducing fuel consumption. Metric: % on-time arrivals for the period
Fewer routing decision errors	A single routing error for a given passage, for example, one that puts the ship in the middle of a severe storm, can negate the entire savings for that season. The objective is to reduce the occurrence of such errors. Metric: standard deviation of fuel consumption for actual route compared to that of optimal route for the period
Reduced excessive motions	Limiting ship motions reduces ship and cargo damage, increases crew comfort, and can reduce a ship's structural maintenance and increase its longevity. Metrics: % occurrence of excessive motions over a threshold for distance travelled, number of reported crew illnesses or accidents due to motion for the period, damage and repair costs for the period, ship life cycle costs
Route optimization including environmentally controlled areas (ECA)	ECAs along national coastlines require switching to cleaner, more costly fuel, and reducing speed. These can impact cost of operation and arrival time. Ship route optimization tools can include ECAs in their calculations to determine the best point to enter an ECA. Metric: Total fuel cost per passage involving ECA.

suggests what measures may provide the best return on investment (ROI). Because some measures generate significant fuel savings at low cost, the net result, even in the first year of implementation, is cost savings. Other measures require significant investment, resulting in a net expense, at least for the first year. Table 3, derived from information in the DNV publication, shows examples of the estimated costs of key candidates for efficiency improvements (i.e., measures projected by DNV to provide potential reduction of at least 15 million tons of CO_2 per year for the world shipping fleet in 2030, or at least 1% of the projected baseline of 1,530 million tons of CO_2 per year).

Meaningful Metrics

The simple act of minimizing bunker consumption and associated carbon emissions while carrying the most cargo the furthest distance seems like it should be a relatively straightforward calculation. Indeed, the IMO recommends that, as a minimum, the relatively straightforward EEOI calculation, first described in MEPC.1/Circ.684, should be used to track efficiency performance according to a ship's SEEMP,

$$\text{EEOI} = \frac{\text{CO}_2 \text{ emission}}{\text{transport work}}$$

where CO_2 emission is calculated by multiplying total fuel consumption by the carbon emission factor for the given fuel type, and transport work is the cargo load multiplied by distance traveled.

Examples of inputs needed for the EEOI calculation are outlined in Table 4. Update frequencies and input sources are suggested, although these are not specified in the IMO guidelines).

TABLE 3

Cost per ton CO_2 averted (based on DNV's *Pathway to Low Carbon Shipping*, 2009).

Measure	Cost/ton CO_2 Averted (US$/ton)
Voyage planning and execution	–$90/ton
Speed reduction (Virtual Arrival and port efficiency)	–$75/ton
Propulsion efficiency improvements	–$65/ton
Trim and draft	–$60/ton
Frequency converters for AC motor speed control	–$50/ton
Contra-rotating propellers	–$40/ton
Weather routing	–$35/ton
Kite-assisted propulsion	$0/ton
Gas fuel (LNG, etc.)	$20/ton
Electronic engine control	$25/ton
Fuel cells as aux engine	$60/ton
Speed reduction coupled with increase in fleet size	$80/ton
Fixed sails/wings	$105/ton
Waste heat recovery	$150/ton
Cold ironing (switching to shore-based power in port)	$200/ton

Figure 1 illustrates typical EEOI calculations over a period of 12 months for an actual container ship making transoceanic passages in the North Pacific. A lower number indicates better efficiency. The higher EEOI values during the winter months may be an indication of the effect of heavy weather on fuel consumption (and carbon emissions), but closer investigation would be needed to rule out other possible causes, such as lower cargo loads during those periods.

While the IMO's EEDI and EEOI focus on carbon emissions, realistically, most commercial shipping companies will be looking at the bottom line, i.e., dollars spent per cargo × distance. Added to this equation is a time factor, for example, "per month," "per season," or "per year." More voyages with higher cargo loads per evaluation period translate into higher efficiency. Currently, this calculation typically uses as a baseline the average fuel consumption from a prior like period, known in the industry as *pro forma*, against which actual consumption is compared. This approach has the obvious shortcoming that it does not take into account variations in the severity of weather encountered in the actual passages. Even when a route is optimized, severe weather conditions have a negative impact on fuel consumption because ships must be diverted around storms or use greater power to overcome strong head seas and winds. Waiting for a storm to pass may result in late arrival, which can translate into delays and fines at the destination port, as well as fewer passages for a given period.

This leads us to consider other benchmarking methods that address the variability of weather conditions and other factors that affect a ship's fuel consumption. In a patent-pending benchmarking methodology developed at Jeppesen,

TABLE 4

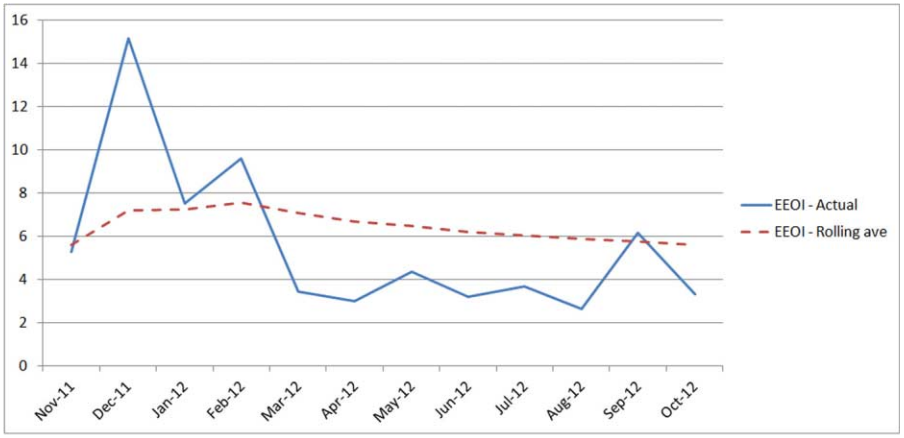
Inputs for EEOI calculation.

Input	Units	Update Frequency	Source of Input
Fuel type and quantity	Depends on fuel type. Examples: 1) Metric tonnes (MT) 2) Million British thermal unit (MMBtu)	Daily	Vessel noon report
Vessel type	Select from: 1) Dry cargo carrier, liquid tanker, gas tanker, ro-ro cargo ship, and general cargo ship 2) Ship carrying combination of containers and other cargos 3) Container ship carrying solely containers 4) Passenger ship 5) Car ferry or carrier 6) Railway or ro-ro vessel	One-time entry per vessel	Initial set-up
Work (cargo)	Depends on vessel type and application. Examples: 1) MT of cargo carried 2) MT of total mass of cargo and containers 3) Number of loaded TEU @ 10MT per TEU plus # empty TEU @ 2MT per TEU, or total # TEU loaded or empty 4) Gross MT of the ship, or # of passengers 5) Number of car units, or occupied lane meters (m) 6) Number of railway cars and freight vehicles, or occupied lane meters	Per passage	Vessel noon report
Distance (GPS position)	Nautical miles (nm) or kilometers (km)	Daily	Vessel noon report
Time for passage	Hours (h)	Daily	Vessel noon report
Time in port	Hours (h)	Daily	Vessel noon report

the fuel efficiency of an actual passage is calculated by comparing the fuel consumption of the actual route taken by the ship against that of the optimal route that could have been taken if one had 20/20 hindsight of the weather, currents, and other factors. The optimal route is calculated using Jeppesen's route optimization software called *Vessel and Voyage Optimization Solution* (VVOS), one of several components that comprise Jeppesen's efficiency management tool suite. VVOS uses advanced routing algorithms, hydrodynamic and performance modeling, and high-resolution ocean forecasts to find the best possible route solutions for a specified range of arrival times that minimize fuel consumption and observe safe operating and user-specified limits. Unlike traditional weather routing, true route optimization incorporates a detailed model of each ship's dynamic motion response and performance characteristics. Weather, wind, wave, and current data, including ensemble forecasts, are considered in finding the optimal route. Forecasts with higher uncertainties result in more conservative solutions than those that are more stable.

FIGURE 1

EEOI for container ship over 12 months.



The resulting optimal route takes into account the actual weather conditions, currents, vessel performance and motion response, and other factors such as user-specified limits, in finding the most fuel-efficient route that arrives at the destination port at the desired time. The benefit of this method is that the baseline or budget against which the ship's actual performance is compared is adjusted to correct for unavoidable factors, such as weather, load conditions, schedule, and mission-specific constraints (Figure 2).

Route simulations using VVOS can also be used to compare different voyage optimization strategies. Figure 3 illustrates that for this particular passage, a savings of 28 tons can be realized simply by using speed management rather than constant RPM.

By comparing ships using a particular efficiency improvement strategy against a control group of ships not using it, the ROI in terms of fuel savings may be determined for that strategy. Figures 4 and 5 illustrate some of the benefits realized using VVOS for route planning and execution. In a comparison of 32 passages using conventional weather routing to 40 similar passages by the same ship class using VVOS, an average of 63 tons of fuel per passage, or about 4% of the total, were saved. Furthermore, the standard deviation, which reflects consistency of routing improvements, was substantially improved, as seen in Figure 5; in over 50% of the passages, fuel consumption was within 0–2% of the optimal route solution. This consistency is what will reliably generate long-term savings, less likely to be negated by gross route planning and/or execution errors.

Some companies are investigating reconfiguring a ship to burn cheaper higher-viscosity bunker fuels, such as IFO 420, 500, 600, or 700 grades instead of the more common IFO 380. Unlike switching to lower-carbon fuels such as LNG, this conversion would not reduce the vessel's EEOI because the carbon emission factors for both viscosities of bunker are essentially equal. Also, such conversions are not without complications; the vessel's power train must be able to accommodate rougher fuel grades and more complex handling issues. (Notwithstanding, there are also issues with using low-emission fuels such as LNG for ship propulsion. LNG has only half the energy density of bunker fuels and therefore requires a greater volume for equivalent energy capacity. Its lower viscosity complicates storage, as sloshing can lead to instability and/or tank damage.) But using IFO 700 instead of IFO 380 could result in a 3-4% reduction in fuel cost, which translates into tens of thousands of dollars for a single transoceanic passage, potentially enough to justify the conversion cost.

Many efficiency metrics that are critical to some companies are only indirectly related, or not at all, to fuel consumption or carbon emissions. Here are some examples:

Quality of operation

- Percent on-time arrival
- Standard deviation of fuel consumption for a given passage
- Number of incidents associated with excessive motion
  - Number and severity of damage incidents
  - Number and severity of crew/passenger motion-related illness or accidents

Cost of operation

- Fuel cost per transport work
- Paid transport work per fleet size
- Actual life cycle cost compared to budget

Port efficiency

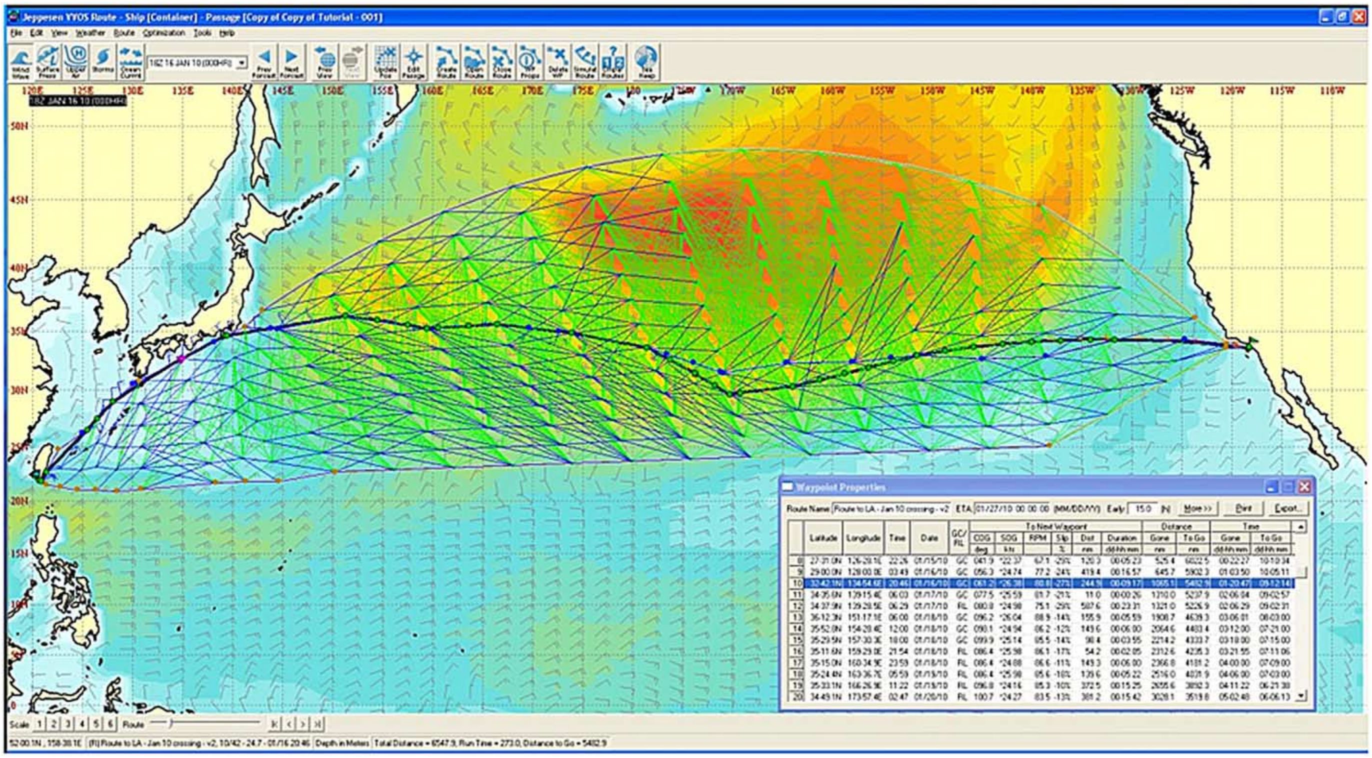
- Time in port saved by reducing speed to delay arrival and avoid port congestion (also known as "Virtual Arrival")
- Total time spent in port/berth
- Cargo loading and unloading efficiency

Maintenance and upgrades

- Adherence to recommended maintenance schedule
- Percent ships in fleet with technology improvements such as onboard route optimization software, low-friction hull coatings, updated autopilot, electronic engine controls, and/or fuel switching

FIGURE 2

Route optimization using VVOS.



To summarize, it seems prudent for a vessel's SEEMP to include the standard EEOI calculation for a general overview of its relative success, as well as secondary metrics that may provide better understanding regarding the cause and effect of various efficiency factors. Using an accepted industry standard metric such as IMO's EEOI allows one to make general comparisons of the vessel's performance with a larger cross-section of the shipping industry. Simple variants of the EEOI, such as a fuel efficiency indicator (that omits the carbon emission factors), and a cost efficiency indicator (that replaces the carbon emission factors with fuel cost factors) may also provide useful insights. By supplementing these basic indicators with more application-specific metrics, one can focus on areas of performance that are of particular interest to the vessel owner and/or operator.

Total Solution Approach—An Example

Evaluating operating efficiency is an elusive, complex process. As an operation becomes more efficient, its interactions become increasingly interdependent; squeeze in one place, and a bulge will appear in another. This is a good sign, because it indicates that little is being wasted. What is important is to maximize efficiency in the areas of highest priority for a given business, while mitigating losses in the less important ones. A comprehensive SEEMP can help operators understand how to do this with confidence of achieving a positive outcome over the long term.

The value of the SEEMP, however, is only as good as the information and insight it provides. In the worst case, it is no more than a superficial report that meets the MARPOL Annex VI requirement. At best, the improvements in operating efficiency will generate significant cost savings that constitute a lucrative ROI.

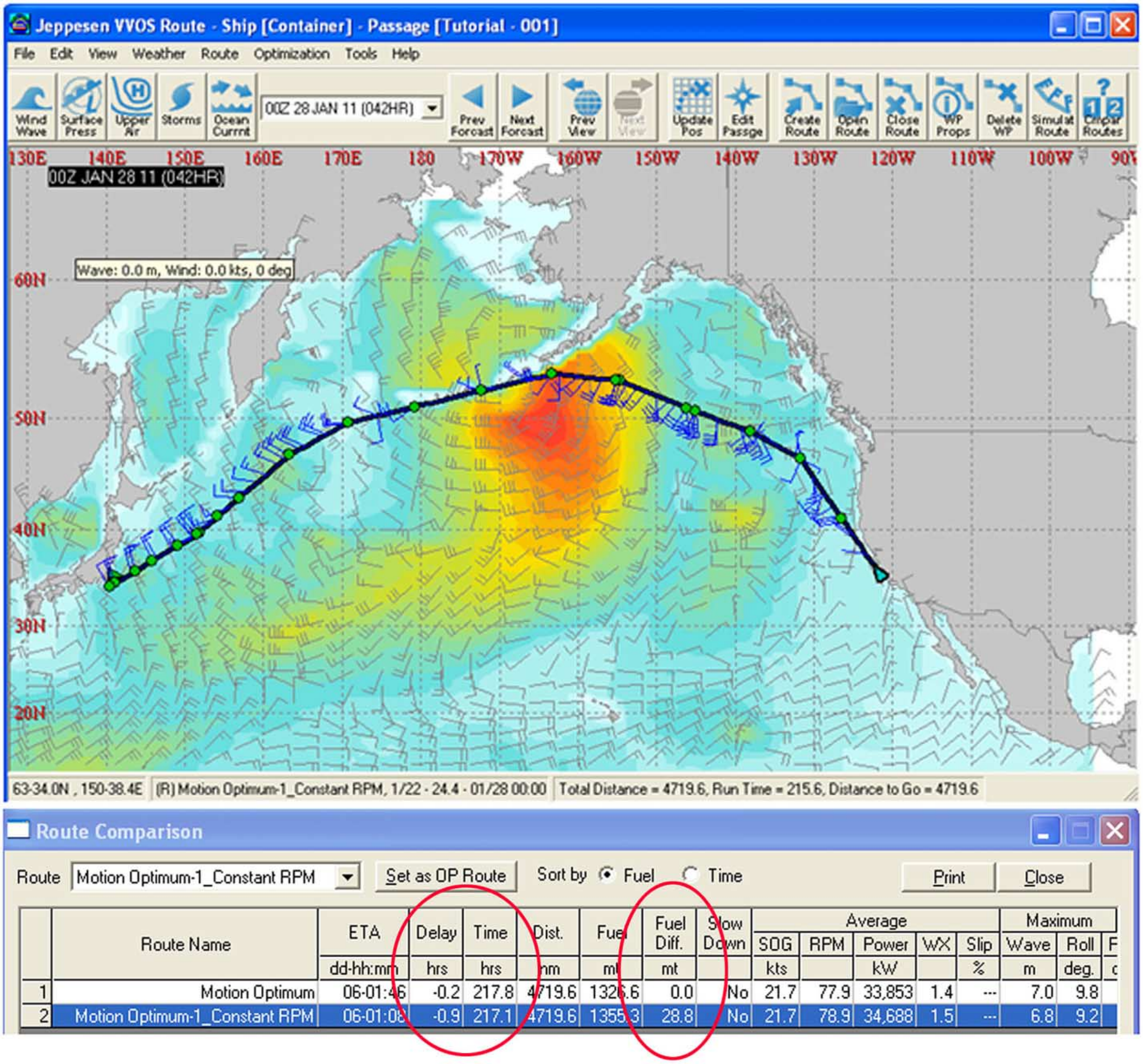
For best results, a total solution approach comprising five main elements is needed:

- Shipboard data acquisition, both automated and manually entered
- Communication method for transmitting the data to shore in a timely manner
- Shore-based analytical tools for processing the data
- Intuitive, easy-to-use displays of data and analytical results, including report-generating capabilities
- Ongoing user training and awareness-raising programs

Jeppesen has developed a suite of integrated software and hardware tools that is designed to address each of these needs. For data acquisition, it includes a user-friendly shipboard event logging

FIGURE 3

VVOS comparison of the same route using speed management and constant RPM strategies. The constant RPM strategy (Route 2) consumes 28 MT more fuel and increases transit time by over 0.5 h.



application for consistent and easy reporting of latest ship operating details. Reporting is facilitated by automating entry of data that are available on the ship's network, supplemented with user-friendly data entry screens for parameters that must be manually entered. These data may be delivered shoreside via the ship's email system; for more frequent and timely updates, a low-cost shipboard data acquisition and communication tool may be used, which monitors and communicates local environmental, performance, and user-entered data to a secure shore-based server using a low earth orbit (LEO) satellite constellation.

Upon arrival at Jeppesen's shore-based server, numerous software tools are applied for storing and analyzing the data. VVOS route optimization software may be employed to find the "optimal route" for a comparison benchmark.

The data and analytical results may be reviewed by operations managers

FIGURE 4

Actual transoceanic passages conducted using traditional weather routing. Total number of passages = 32; mean value = 5.36%; excess tons fuel consumed compared to "optimal route" = 85.

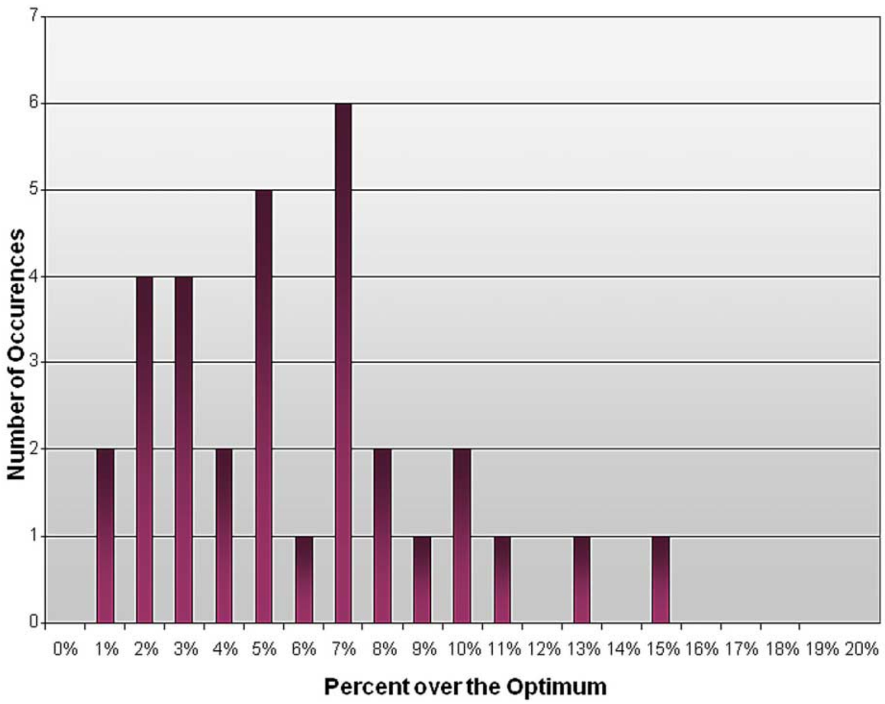
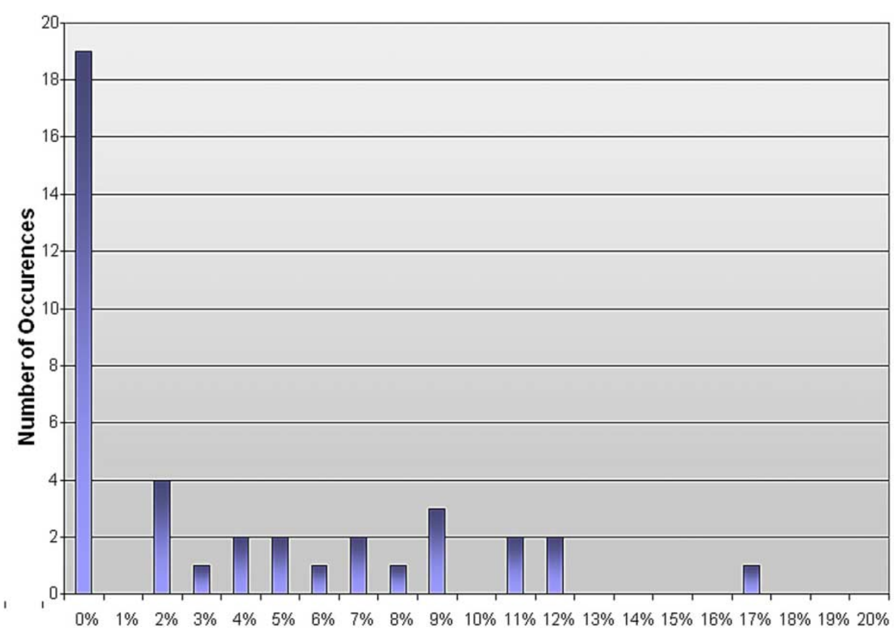


FIGURE 5

Actual transoceanic passages conducted using VVOS. Total number of passages = 40; mean value = 2.16%; excess tons fuel consumed compared to "optimal route" = 22.



using a shore-side fleet management utility that integrates fleet-wide voyage data into a single database. This secure Web-based system provides operations managers with a user-friendly dashboard that allows them to quickly determine which vessels in their fleet are having issues. The tool provides the ability to track vessels routes, ETA reliability, fuel analysis, and weather forecasts, and publish reports tailored to the customer's needs, including SEEMP results, at the press of a button (Figure 6).

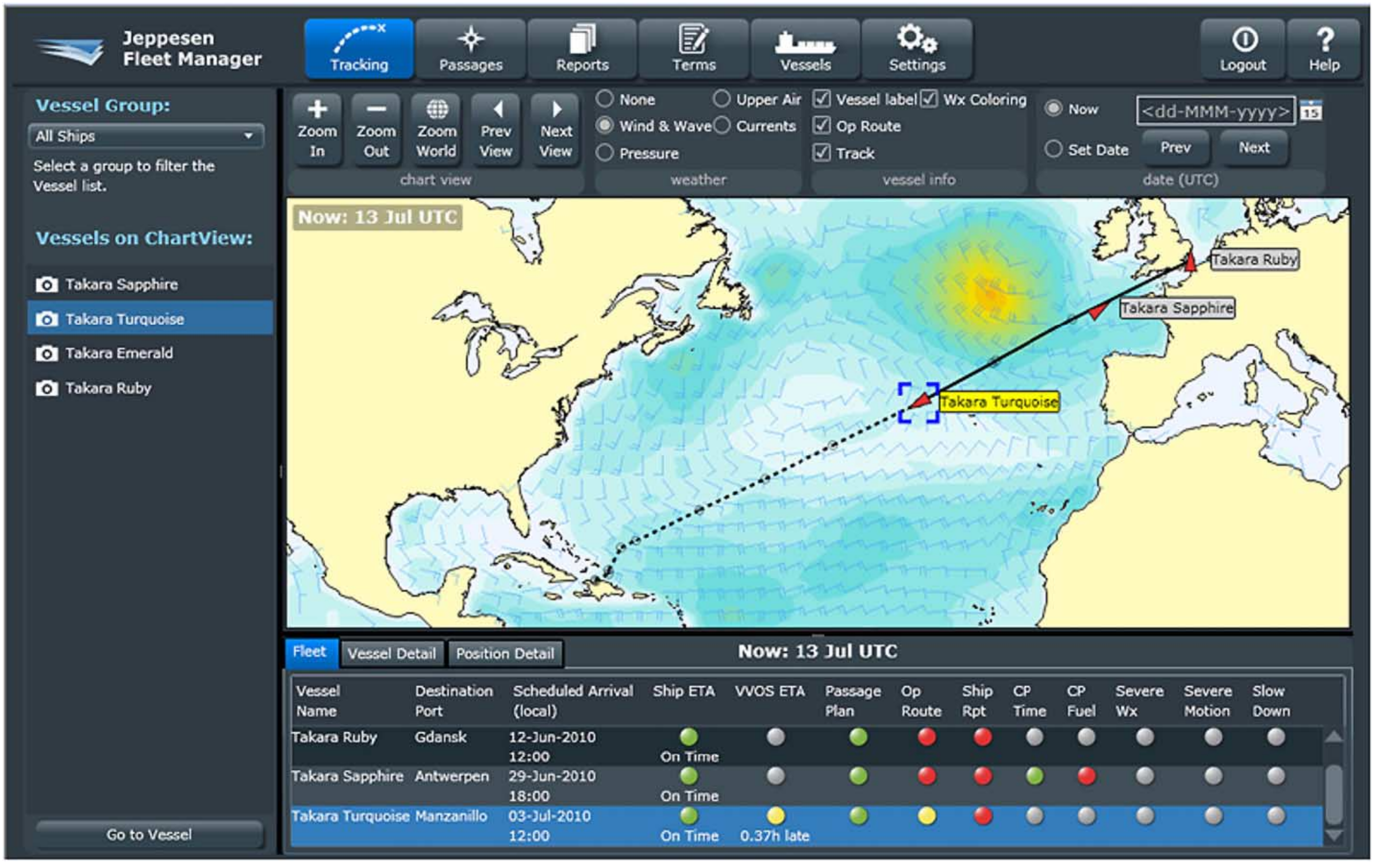
Training and Raising Awareness

Two aspects of an efficiency management program that are often overlooked or undervalued are training and raising awareness. Both IMO and OCIMF emphasize this in their publications. It is not enough for only the captain and officers to support the effort. An overarching culture of conservation aboard the ship should be developed through training, supplemented with simple promotions such as encouraging the use of waste recycling facilities and turning off unnecessary lighting. Special incentives such as rewarding crews that provide the greatest energy savings and recognizing individuals with "green ship" awards and training certificates may help motivate shipboard personnel to support the program.

New tools intended to improve efficiency will require training for their proper and effective use. This training should be repeated regularly to accommodate captains and crew cycling between ship and shore. A captain returning to the ship after several months leave may not feel comfortable with the new procedures and so may revert to older, more familiar operating methods. To help prevent this, a company's efficiency management program must be strongly

FIGURE 6

FleetManager dashboard.



supported throughout the highest levels of management, with regular audits to ensure that it is being adhered to.

In this age of cost cutting and crew reduction, new processes implemented on the ship will be poorly received unless they offer at least the perception of a net reduction in work load. This important human factor can make the difference between success and failure of a new initiative such as efficiency management and can only be solved with intimate domain knowledge of the shipboard working environment. Duplication of effort with existing processes that already exist on the ship will be quickly perceived as such and accepted only with reluctance. For example, if a ship already provides manually prepared noon reports and is now required to add daily SEEMP updates, the SEEMP tool should be able to also process the noon reports as a matter of course, and ideally, streamline the process through automated data entry and report generation. A good design goal for developers of shipboard software should be that every new product will provide a net reduction of the captain and crew's workload.

Where Do We Go From Here?

While good progress is being made on multiple fronts in efficiency management, one area still presents significant difficulties—that of fleet deployment management and logistics. This is the problem of optimizing the assignment of ships to passages and cargo to ships to maximize operating efficiency and profit. Objectives include, for example, matching the best-suited vessels and crews for each specific voyage, minimizing ballast voyages (transporting empty vessels, containers, and crews to where they are needed), efficient loading and unloading of cargo in port, optimizing "bunkering" or refueling, and recovering quickly from schedule disruptions caused by heavy weather and equipment malfunctions. Several independent studies suggest that this type of transportation management has the greatest potential for efficiency gains, as much as 50%, compared with other technological and operational measures, which typically range from 1% to 10% (Alvik et al., 2009; IMO, 2009c; Poulovassilis, 2010).

Optimizing fleet deployment is not unlike the problem encountered in the commercial aviation industry. Solving it involves a large number of variables and constraints that change with every deployment. Toward this end, Jeppesen engineers, in concert with Boeing Research and Technology, are developing new advanced optimization processes that will be especially useful in both the aviation and maritime industries, for fleet deployment management, routing of vessel convoys, and other applications where multiple objectives must be satisfied.

Conclusion

Management of ship operating efficiency, due to its complex interactions, must be an integrated total solution that extends across the entire operation of the fleet. No single metric can be used to indicate success or failure of improving overall efficiency. Rather, a comparative analysis of multiple metrics is required. Furthermore, to be viable, efficiency management must accommodate operating objectives, priorities, and constraints.

While new regulations such as the MARPOL SEEMP requirement are steps in the right direction for improving ship operating efficiency, such measures are only as good as the information and insights they provide. When properly designed and implemented, they will generate significant savings that constitute lucrative returns on investment. For best results, a total solution approach should include these ten steps for success:

- Develop and maintain a comprehensive plan, including careful selection of relevant key performance indicators for measuring efficiency performance.
- Clearly define quantifiable metrics, along with the required inputs and methods of obtaining the data.
- Set realistic goals for each evaluation period to measure rates of success. These goals should be adjusted regularly to accommodate relative progress and changes in objectives.
- Use historical data from the ship's log to establish existing performance baselines and identify areas obviously needing improvement.
- Facilitate accurate data acquisition for shipboard performance monitoring, including automated data entry and error-checking where possible, supplemented with office-supplied shore-based data.
- Utilize a reliable communication method for transmitting shipboard data to shore in a timely manner.
- Implement advanced analytical tools for shore-based processing of the data.
- Enable constructive, intuitive evaluation of the results through easy-to-use information visualization tools and displays.
- Include automated report-generating tools for dissemination of results, recommendations, and auditing purposes.
- Maintain a robust user training and awareness-raising program with support at all levels of management.

In such a complex and evolving process, one cannot simply deliver a product and expect it to fulfill the customer's expectations for very long. Rather, producing good results repeatedly over the long term requires working closely with each customer on an ongoing basis. Toward this end, service providers in this industry must also offer comprehensive customer support and consulting services. In addition to assisting with developing and implementing efficiency management programs, related professional services may include, for example, around-the-clock ship routing guidance, product deployment and maintenance support, and special case studies such as incident investigations and other voyage analyses involving route simulations using historical weather data. To enhance user skills and awareness, training, workshops, and seminars should be offered regularly on relevant maritime topics, including efficiency management, heavy weather damage avoidance, and advanced product application techniques.

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