
Certificate in Vessel Performance Management (India)

Performance Monitoring and Analysis

Vessel performance monitoring is the systematic process of collecting, analysing and interpreting data that describe how a ship operates under various conditions. The purpose is to identify opportunities for fuel savings, improve operational efficiency and ensure compliance with regulatory and commercial targets. In the context of the Certificate in Vessel Performance Management (India), a solid grasp of the terminology is essential because each term represents a specific measurement, calculation or concept that feeds into the overall performance picture. The following exposition defines the key terms, illustrates their practical use, highlights typical challenges and links them to the broader analytical framework.

Fuel consumption refers to the quantity of fuel burned by a vessel's propulsion and auxiliary systems over a defined period. It is usually expressed in tonnes per day (t/d) or kilograms per hour (kg/h). Accurate fuel consumption data are obtained from flow meters, fuel oil transfer records or fuel management software. For example, a bulk carrier that reports a fuel consumption of 30 t/d while steaming at 13 knots can be compared with its design fuel consumption of 28 t/d to assess the efficiency gap. Common challenges include measurement errors caused by fouled flow meters, temperature correction inaccuracies and delays in data entry that can distort trend analysis.

Specific fuel consumption (SFC) is the amount of fuel required to produce one unit of power, typically expressed as grams per kilowatt-hour (g/kWh) for diesel engines. SFC provides a direct indicator of engine efficiency independent of vessel speed or load. If a main engine delivers 10 MW of power and consumes 2 800 kg of fuel in one hour, the SFC is 280 g/kWh. Lower SFC values denote better engine performance. In practice, operators monitor SFC to detect deviations caused by engine wear, sub-optimal fuel quality or incorrect engine settings. The main difficulty lies in obtaining precise power output data, especially when the engine is operated under varying load conditions.

Trim describes the longitudinal inclination of a ship, measured as the difference between the forward and aft drafts. Positive trim (aft-heavy) means the stern sits deeper in the water, while negative trim (bow-heavy) indicates the opposite. Trim influences resistance, propeller immersion and fuel consumption. A typical example is a container vessel that reduces its SFOC by 0.5 % By adjusting ballast to achieve a slight aft-trim of 0.3 M. Determining the optimal trim requires a combination of hydrostatic calculations, trim-induced resistance corrections and real-time monitoring. The principal challenge is the dynamic nature of trim, which can change with cargo loading, ballast operations and sea state, making continuous measurement essential.

Draft is the vertical distance from the waterline to the bottom of the keel at a specific location, usually measured at the forward and aft perpendiculars. Draft is a primary indicator of the ship's loading condition and is used to calculate displacement, cargo weight and stability parameters. For instance, a tanker with a forward draft of 12.5 M and an aft draft of 13.0 M has a mean draft of 12.75 M, which can be correlated with the ship's hydrostatic tables to determine the current displacement. Accurate draft measurement is critical for compliance with draft limits in shallow ports and for optimizing ballast distribution. Errors can arise from

wave-induced fluctuations, sensor misalignment and human reading inaccuracies.

Displacement is the total weight of the water displaced by the vessel, equal to the vessel's own weight plus cargo, fuel, provisions and ballast. It is expressed in tonnes and can be derived from draft readings using the ship's hydrostatic curves. For example, a bulk carrier at a mean draft of 13.2M may have a displacement of 65 000 t according to its hydrostatic tables. Displacement data are essential for calculating resistance, propulsion power and fuel consumption per tonne of cargo. A common difficulty is the need to update hydrostatic tables when modifications such as hull retrofits or equipment additions alter the vessel's weight distribution.

Resistance is the force opposing a ship's forward motion, generated by water friction, wave making, air resistance and, in some cases, hull appendages. It is measured in kilonewtons (kN) or as a coefficient (C_f). Total resistance (RT) can be expressed as the sum of frictional resistance (R_f), wave-making resistance (R_w) and added resistance components such as wind resistance (R_a). For a vessel traveling at 14 knots, the total resistance may be calculated as 1 200 kN, of which 800 kN is frictional and 400 kN is wave-making. Resistance is a fundamental parameter because propulsion power is directly proportional to $RT \times \text{ship speed}$. Accurate resistance estimation requires knowledge of hull form, surface condition, sea state and speed, and errors often stem from neglecting the impact of fouling or from using outdated empirical formulas.

Propulsion power is the mechanical power delivered by the engine to the propeller, expressed in kilowatts (kW) or megawatts (MW). It is the product of torque and rotational speed, and it must overcome the ship's total resistance at the given speed. If a vessel experiences a total resistance of 1 200 kN at 14 knots (7.2 M/s), the required propulsion power is approximately 8 640 kW ($P = R \times V$). Propulsion power is a central factor in performance analysis because it determines the fuel consumption needed to maintain a schedule. In practice, operators compare the required power with the actual engine output to evaluate efficiency. Challenges include accounting for propeller slip, thrust deduction and hull-propeller interaction, which can cause discrepancies between theoretical and measured power.

Effective power (PE) is the power needed to overcome the ship's resistance at a given speed, without considering losses in the propulsion system. It is calculated as $PE = RT \times V$, where RT is total resistance and V is ship speed. Using the previous example, PE would be 8 640 kW. Effective power provides a baseline for assessing how much additional power is consumed by the propulsion machinery.

Delivered power (PD) is the power actually supplied by the engine to the propeller shaft, after accounting for mechanical losses in the transmission, bearings and gearboxes. It is higher than effective power because it must compensate for these losses. If the overall propulsion efficiency (η_p) is 0.70, The delivered power is $PE / \eta_p \approx 12\,340$ kW. Understanding the difference between PE and PD helps identify where efficiency improvements can be made, such as upgrading bearings or reducing gear friction.

Propulsive efficiency (η_p) is the ratio of effective power to delivered power, reflecting how effectively the propulsion system converts shaft power into thrust. It is expressed as a percentage. For a typical modern vessel, η_p may range from 0.60 To 0.75. High propulsive efficiency indicates that the propeller and hull form are well matched. Operators monitor η_p to detect degradation caused by fouling, propeller damage or

sub-optimal operating points.

Hull efficiency (η_h) accounts for the interaction between the hull and propeller, incorporating thrust deduction (t) and wake fraction (w). It is calculated as $\eta_h = (1 - t) / (1 - w)$. Thrust deduction represents the loss of thrust due to the hull's resistance to the propeller's induced flow, while wake fraction represents the reduction in inflow velocity at the propeller because of the hull's boundary layer. For a vessel with $t = 0.1$ and $w = 0.2$, $H_h = 0.9 / 0.8 = 1.125$, indicating a beneficial hull-propeller interaction. Accurate estimation of t and w requires model tests or CFD analysis; errors in these parameters can lead to significant miscalculations of overall efficiency.

Total propulsive efficiency (η_t) combines propulsive, hull and mechanical efficiencies, representing the overall conversion of fuel energy into useful ship motion. It is calculated as $\eta_t = \eta_p \times \eta_h \times \eta_m$, where η_m is the mechanical efficiency of the engine-propulsion train. Typical values for modern vessels are in the range of 0.45–0.55. Monitoring η_t over time enables the identification of trends related to hull fouling, engine wear or operational practices.

Engine load factor (ELF) is the ratio of the actual engine power output to the engine's rated maximum power. It indicates how heavily the engine is being utilized. An ELF of 0.70 means the engine is operating at 70% of its design capacity. Maintaining an ELF within an optimal band (often 0.70–0.85) helps avoid excessive wear, improves fuel efficiency and reduces emissions. Operators may adjust speed or ballast to keep ELF within this band, especially on long voyages where fuel cost savings are significant.

Power utilisation factor (PUF) measures the proportion of available power that is effectively used for propulsion, taking into account auxiliary loads and idle periods. It is expressed as a percentage and is calculated as $(\text{Power used for propulsion} / \text{Total engine power}) \times 100$. A high PUF indicates that most of the engine's capacity is dedicated to moving the ship, whereas a low PUF may signal that auxiliary equipment is consuming a disproportionate share of power, perhaps due to inefficient HVAC or lighting systems.

Fuel oil consumption (FOC) reporting is the process of documenting fuel usage in a standardized format, often required for regulatory compliance (e.g., IMO DCS) and for internal performance analysis. The report typically includes total fuel burned, fuel type, operating hours, engine load and voyage details. Accurate FOC reporting enables benchmarking against industry standards and facilitates carbon accounting. Errors frequently arise from inconsistent units, failure to correct for temperature and density variations, or omission of auxiliary fuel consumption.

Energy efficiency design index (EEDI) is a regulatory metric that quantifies the CO₂ emissions per tonne-nautical mile for newly built ships. It is expressed in grams of CO₂ per tonne-nautical mile (g CO₂/t·nm) and is calculated based on the ship's design parameters, such as deadweight, speed, and installed power. For a vessel with a deadweight of 50 000 t and a design speed of 15 kn, the EEDI might be 12 g CO₂/t·nm. Although the EEDI is a design-stage indicator, understanding its components helps operators appreciate the impact of operational choices on emissions.

Carbon intensity indicator (CII) is an operational metric introduced by IMO to monitor the CO₂ emissions of ships during service. It is expressed as grams of CO₂ per tonne-nautical mile and is calculated from actual

fuel consumption, cargo carried and distance traveled. A vessel that burns 30 t of fuel over a 10 000 nm voyage while carrying 40 000 t of cargo will have a CII of approximately 6 g CO₂/t-nm. Operators aim to keep CII below the annual rating threshold to avoid penalties. Challenges include ensuring accurate cargo data, handling multi-leg voyages and reconciling fuel quality variations.

Vessel speed is the speed of the ship relative to the water, commonly measured in knots (nautical miles per hour). Speed is a key variable in performance analysis because resistance increases roughly with the square of speed, while power requirement grows with the cube of speed. For example, increasing speed from 12 kn to 14 kn may raise fuel consumption by 30 % due to the cubic relationship. Speed management programmes, such as “slow steaming,” exploit this relationship to achieve fuel savings. Precise speed measurement relies on GPS data, which must be filtered to remove short-term fluctuations caused by wave motion.

Course over ground (COG) and heading are navigational terms that influence performance monitoring. COG is the actual track of the vessel over the earth’s surface, while heading is the direction the vessel’s bow points. The difference between them, called drift, results from wind and current. When analysing fuel consumption, it is important to separate speed through water from speed over ground, because the former determines resistance while the latter determines schedule adherence.

Wind resistance (R_a) is the component of total resistance caused by aerodynamic drag from the wind acting on the superstructure and hull above the waterline. It is calculated using the wind speed, projected area and a drag coefficient. For a vessel with a wind speed of 15 m/s and a projected area of 2 000 m², R_a may be around 150 kN. Wind resistance becomes significant in high-wind regions such as the Bay of Bengal, and it can be mitigated by route planning or by adjusting trim to reduce exposed area.

Current effect refers to the influence of ocean currents on a vessel’s speed through water and fuel consumption. A favourable current reduces required propulsion power, while an adverse current increases it. When analysing performance, the effective speed (speed through water) must be corrected for current to obtain the true resistance-related power demand. The challenge lies in obtaining accurate current data, which may be provided by satellite altimetry or numerical weather models, and in integrating this data into the performance monitoring system.

Fouling factor quantifies the additional resistance caused by marine growth on the hull. It is expressed as a percentage increase over the clean-hull resistance. A fouling factor of 10 % means the vessel experiences 10 % more resistance due to bio-fouling. Fouling can increase fuel consumption by 5–15 % depending on the vessel type and operating speed. Monitoring fouling involves periodic hull inspections and comparing measured resistance or fuel consumption against baseline clean-hull values. Managing fouling through regular cleaning or anti-fouling coatings is a key area for cost reduction.

Propeller slip is the difference between the theoretical advance of the propeller (based on its pitch) and the actual advance achieved in water. High slip indicates that the propeller is not converting shaft rotation efficiently into thrust, often due to cavitation, fouling or improper pitch. For a propeller with a pitch of 1.5 M rotating at 100 rpm, the theoretical advance per minute is 150 m, while the actual advance may be 120 m, resulting in a slip of 20 %. Reducing slip can improve propulsive efficiency and lower fuel consumption.

Thrust deduction factor (t) and wake fraction (w) have already been introduced, but they deserve separate emphasis because they are often sources of confusion. The thrust deduction factor represents the loss of thrust due to the hull's resistance to the propeller's induced flow, while wake fraction represents the reduction in inflow velocity at the propeller because of the hull's boundary layer. Both factors are dimensionless and typically range from 0.05 To 0.15 For large merchant vessels. Accurate values are obtained from model testing, CFD simulations or empirical correlations. Misestimating t or w can lead to errors of several percent in propulsive power calculations.

Power plant load factor (PLF) is the ratio of the actual electrical power generated by the ship's generators to their combined rated capacity. It is used primarily for evaluating the efficiency of auxiliary power systems, such as when a vessel operates at low speeds and relies heavily on auxiliary generators. A PLF of 0.30 Indicates that only 30% of the generator capacity is being used, which may be inefficient if the generators have a minimum efficient load. Operators may consolidate loads onto fewer generators to improve overall plant efficiency.

Auxiliary power consumption (APC) encompasses the fuel used by non-propulsion systems, including refrigeration, cargo handling equipment, lighting, navigation electronics and hotel services. APC is expressed in tonnes per day and is a significant part of total fuel consumption, especially for refrigerated cargo carriers and cruise ships. For a refrigerated cargo vessel, APC may account for 10–15% of the total fuel burned. Reducing APC involves measures such as variable frequency drives for pumps, energy-efficient lighting and better insulation of refrigerated spaces.

Fuel oil quality influences combustion efficiency, emissions and engine wear. Key quality parameters include viscosity, density, sulfur content, calorific value and water content. Low-sulfur fuel ($\leq 0.5\% \text{ M/m}$) reduces SOx emissions but may have a lower calorific value, requiring higher volume to produce the same power. High viscosity can cause poor atomisation in the fuel injectors, leading to incomplete combustion and higher SFC. Monitoring fuel quality at the bunker point and adjusting engine settings accordingly is essential for maintaining optimal performance.

Calorific value (CV) is the amount of energy released per unit mass of fuel when it is completely combusted, expressed in megajoules per kilogram (MJ/kg). Marine diesel oil typically has a CV of 42–44 MJ/kg, while heavy fuel oil may have a CV of 39–41 MJ/kg. The CV is used to convert fuel mass consumption into energy terms, which are required for emissions calculations. Temperature and pressure corrections must be applied to the measured CV to ensure consistency with standard conditions.

Temperature correction factor (TCF) adjusts fuel volume measurements to a reference temperature, usually 15 °C, because fuel density changes with temperature. The formula $\text{TCF} = 1 / [1 + \alpha \times (T - 15)]$ where α is the thermal expansion coefficient ($\approx 0.0008 \text{ } ^\circ\text{C}^{-1}$ for heavy fuel oil) and T is the measured temperature. Failure to apply TCF can lead to systematic over- or under-estimation of fuel consumption, especially in tropical regions where sea-water temperatures often exceed 30 °C.

Density correction factor (DCF) accounts for variations in fuel density due to blending of different fuel grades. It is calculated as $\text{DCF} = \rho_{\text{ref}} / \rho_{\text{meas}}$, where ρ_{ref} is the reference density and ρ_{meas} is the measured density. Accurate density measurement is performed using a densitometer at the bunker terminal.

Energy management system (EMS) is a software platform that integrates data from engine sensors, fuel flow meters, GPS, weather services and cargo information to provide real-time performance indicators. An EMS can generate alerts when fuel consumption deviates from the baseline, suggest optimal trim settings, and produce daily performance reports. Implementation of an EMS requires careful sensor calibration, data validation routines and crew training. Common challenges include data latency, integration with legacy shipboard systems and resistance to change among crew members.

Key performance indicator (KPI) in vessel performance monitoring is a quantifiable metric that reflects the vessel's operational efficiency. Typical KPIs include SFC, fuel consumption per nautical mile, CII, ELF, PUF and CO₂ emissions per tonne-nautical mile. Setting realistic KPI targets involves benchmarking against similar vessels, historical performance and regulatory limits. Over-reliance on a single KPI can be misleading; for example, focusing solely on reducing SFC may lead to unacceptable delays if speed is compromised.

Benchmarking is the process of comparing a vessel's performance against a reference set of vessels, often grouped by type, size, age and operating profile. Benchmarking can reveal whether a ship is under-performing due to hull fouling, sub-optimal engine settings or operational practices. The outcome of benchmarking is typically presented as a deviation percentage, such as "fuel consumption is 8% higher than the class average." Effective benchmarking requires a robust database, consistent data cleaning procedures and consideration of external factors such as weather and cargo variations.

Voyage data recorder (VDR) is a mandatory device that records a ship's navigational and operational data, similar to an aircraft black box. While its primary purpose is accident investigation, VDR data can also be mined for performance analysis, providing accurate speed, heading, draft and engine parameters over the entire voyage. Access to VDR data enables post-voyage audits and validation of real-time monitoring systems. The main limitation is data privacy and the need for specialised software to extract performance-relevant parameters.

Weather routing involves the use of meteorological forecasts and oceanographic models to select a route that minimizes fuel consumption while meeting schedule constraints. By avoiding headwinds, strong currents or rough seas, a vessel can achieve significant fuel savings. For example, a weather-routing service may suggest a 150 nm deviation that reduces fuel consumption by 2% on a 5 000 nm voyage. Integrating weather routing recommendations into the performance monitoring workflow requires coordination between the ship's navigation officer and the operations team.

Hull cleaning schedule is a planned programme for removing marine growth from the hull, typically performed during dry-dock periods or using in-water cleaning methods. The schedule is based on the expected fouling rate, operational area and economic analysis of fuel savings versus cleaning cost. A typical schedule for a mid-size bulk carrier operating in tropical waters may call for hull cleaning every 12 months, resulting in an estimated fuel saving of 1% to 3%.

Hull coating performance refers to the effectiveness of anti-fouling paints in preventing marine growth. Performance is measured by the fouling factor over time and by the durability of the coating under mechanical abrasion. Advances in coating technology, such as silicone-based foul-release paints, aim to reduce frictional resistance without the environmental concerns associated with biocidal paints. Selecting an

appropriate coating requires evaluation of the ship's operating profile, regulatory restrictions on biocide content and cost-benefit analysis.

Engine condition monitoring employs sensor data such as cylinder pressure, exhaust temperature, vibration and oil analysis to assess the health of the main engine. Abnormal trends can indicate wear, combustion inefficiency or impending failure. For instance, an increase in cylinder pressure variance may signal piston ring wear, which can degrade SFC by several percent. Early detection through condition monitoring allows proactive maintenance, avoiding costly downtime and preserving fuel efficiency.

Combustion optimisation involves adjusting engine parameters—fuel injection timing, air-fuel ratio, turbocharger boost—to achieve the lowest possible SFC while meeting emission limits. Modern engines are equipped with electronic control units (ECUs) that can be tuned for specific operating points. A common optimisation practice is “low-load tuning,” where the engine is calibrated for optimal efficiency at the typical cruise load (e.G., 70 % Of rated power). The challenge lies in balancing fuel efficiency with emission regulations, as leaner combustion can raise NO_x emissions.

Emission monitoring is the systematic measurement of pollutants such as CO₂, SO₂, NO_x and particulate matter. CO₂ emissions are directly linked to fuel consumption via the fuel's carbon content, while SO₂ depends on sulfur content. NO_x emissions are a function of combustion temperature and pressure, often controlled by exhaust gas recirculation (EGR) or selective catalytic reduction (SCR). Accurate emission monitoring supports compliance with IMO MARPOL Annex VI, facilitates carbon accounting and can be used to verify the effectiveness of fuel-switching strategies.

Carbon accounting is the process of quantifying a vessel's greenhouse-gas emissions for reporting, trading or internal management purposes. It requires conversion of fuel consumption data into CO₂ equivalents using emission factors (e.G., 3.114 Kg CO₂ per kg of diesel). Carbon accounting may also include upstream emissions from fuel production (“well-to-tank”) if the organization adopts a full-life-cycle approach. The resulting carbon footprint can be used to set reduction targets, purchase offsets or demonstrate corporate sustainability.

Energy efficiency operational index (EEOI) is a performance metric introduced by some classification societies that combines fuel consumption, cargo carried and distance travelled into a single figure. It is calculated as $(\text{Fuel consumption} \times \text{Emission factor}) / (\text{Cargo carried} \times \text{Distance})$. An EEOI of 0.3 G CO₂/t-nm indicates higher efficiency than an EEOI of 0.5 G CO₂/t-nm. Ship operators use EEOI to track progress toward internal sustainability goals and to compare vessels across a fleet.

Ship-to-shore data exchange refers to the transmission of performance data from the vessel to shore-based systems via satellite, radio or cellular networks. This enables real-time fleet management, remote troubleshooting and integration with shore-based analytics platforms. The data typically include speed, draft, fuel flow, engine load and weather conditions. Ensuring data integrity during transmission is critical; common issues involve bandwidth limitations, latency and security concerns.

Data validation is the set of procedures used to verify the accuracy, completeness and consistency of performance data before analysis. Validation steps may include range checks (e.G., Fuel flow must be

between 0 and 500 kg/h), cross-checking of draft against cargo weight, and detection of out-liers using statistical methods. Robust data validation prevents misleading conclusions and supports credible reporting.

Statistical analysis in vessel performance involves techniques such as regression, time-series analysis and variance analysis to identify trends, correlations and root causes of inefficiency. For example, a regression model might reveal that fuel consumption increases by 0.1 T per nautical mile for every 0.5 M increase in aft draft, highlighting the importance of trim optimisation. Advanced analytics may employ machine-learning algorithms to predict fuel consumption based on a combination of speed, weather, load and hull condition.

Root-cause analysis (RCA) is a systematic approach to uncover the underlying reasons for performance deviations. Techniques such as the "5 Whys" or fishbone diagrams help isolate factors like engine wear, ballast mis-distribution or inaccurate weather forecasts. Conducting RCA after an unexpected fuel consumption spike enables targeted corrective actions, such as recalibrating flow meters or revising the voyage plan.

Corrective action plan (CAP) outlines the steps required to address identified performance issues. A CAP typically includes a description of the problem, the responsible party, a timeline for implementation and measurable targets. For instance, if a CAP targets excessive fuel consumption due to hull fouling, the actions may involve scheduling an in-water cleaning, updating the fouling factor in the performance model and monitoring fuel consumption for the next two voyages to confirm improvement.

Continuous improvement cycle (Plan-Do-Check-Act) is a management philosophy applied to vessel performance. "Plan" involves setting targets and developing strategies; "Do" is the implementation of actions; "Check" consists of monitoring KPIs and analysing results; "Act" includes adjusting processes based on the findings. This cyclical approach ensures that performance gains are sustained and that new opportunities are constantly explored.

Operational envelope defines the range of permissible operating conditions for a vessel, such as speed limits, draft restrictions, engine load limits and emission caps. Staying within the operational envelope is essential for safety, regulatory compliance and efficient performance. For example, a vessel operating in a draught-restricted port must adjust ballast to meet a maximum draft of 12.5 M, which may affect trim and consequently fuel consumption.

Speed-fuel curve is a graphical representation that shows the relationship between vessel speed and fuel consumption. It typically displays a cubic relationship, where a modest increase in speed results in a disproportionately larger increase in fuel use. The curve is used to determine the most economical speed for a given voyage, often called the "optimum speed." Generating an accurate speed-fuel curve requires data collection over a range of speeds, ideally under similar weather and load conditions.

Power-speed curve illustrates how required propulsion power varies with vessel speed. It is derived from resistance calculations and is essential for engine sizing and for evaluating the impact of speed changes on engine load. The curve helps in selecting an engine that can meet the design speed while operating efficiently at lower, more economical speeds.

Voyage optimisation combines speed, route, trim and weather considerations to minimise total cost of

transport, which includes fuel, time penalties and emissions charges. Modern optimisation software integrates real-time data, forecast models and cost parameters to propose a plan that balances fuel savings against schedule adherence. Implementation of the plan requires coordination among the master, chief engineer and shore-based operations team.

Fuel surcharge is an additional cost applied by charterers or freight forwarders to compensate for fluctuations in fuel prices. While not a performance metric per se, understanding fuel consumption patterns helps operators negotiate fair surcharges and manage cash flow. For example, a vessel that demonstrates a 5 % lower SFC than the fleet average may be able to justify a reduced surcharge.

Carbon tax is a governmental levy on CO₂ emissions, often calculated based on fuel consumption and carbon content. In regions where carbon taxes are applied, fuel efficiency directly impacts operating costs. Accurate monitoring of fuel consumption and carbon intensity is therefore essential for budgeting and for evaluating the financial benefit of efficiency measures such as hull cleaning or slow steaming.

Regulatory compliance in performance monitoring includes adherence to IMO DCS (Data Collection System), EEDI, CII, MARPOL Annex VI limits on sulfur and nitrogen oxides, and regional carbon pricing mechanisms. Non-compliance can result in fines, detention or denial of entry. Performance data must be retained for at least five years and be readily available for audit.

Data archiving is the practice of storing performance data in a secure, searchable format for future reference, compliance verification and trend analysis. Archiving solutions should support metadata tagging (vessel, voyage, date) and provide redundancy to prevent loss.

Stakeholder communication involves presenting performance results to owners, operators, charterers and regulatory bodies in a clear and actionable format. Effective communication often uses visual aids such as dashboards, but the underlying data must be accurate and validated.

Training and competence are critical for ensuring that crew members understand the importance of accurate data collection, can operate monitoring equipment correctly and can interpret performance indicators. Training programmes should cover sensor calibration, data entry procedures, basic fuel-efficiency concepts and the use of the EMS.

Human factors influence performance monitoring through habits, workload and organizational culture. For instance, a crew that routinely neglects to record fuel deliveries may create gaps in the data, leading to erroneous analysis. Addressing human-factor issues may involve simplifying procedures, automating data capture and fostering a culture of continuous improvement.

Digital twin is an emerging concept where a virtual replica of the vessel, built from real-time data, simulates performance under various scenarios. The digital twin can predict the impact of changes in speed, trim or weather on fuel consumption, enabling proactive decision-making. Implementing a digital twin requires high-resolution sensor data, robust modelling tools and integration with the ship's EMS.

Risk assessment in performance monitoring identifies potential sources of error, data loss or operational disruption. Typical risks include sensor failure, cyber-security breaches, regulatory changes and extreme

weather events. A risk register should be maintained, with mitigation strategies such as redundant sensors, regular software updates and contingency plans for data recovery.

Key technical terms summary

- Resistance – total force opposing motion; sum of frictional, wave-making and added components.
- Specific fuel consumption – fuel per unit power; indicator of engine efficiency.
- Trim – longitudinal inclination; affects resistance and propeller immersion.
- Draft – vertical distance from waterline to keel; basis for displacement calculation.
- Displacement – total weight of ship and cargo; used to compute resistance.
- Propulsion power – mechanical power required to overcome resistance at a given speed.
- Effective power – power needed to overcome resistance; baseline for efficiency calculations.
- Delivered power – shaft power after accounting for mechanical losses.
- Propulsive efficiency – ratio of effective to delivered power.
- Hull efficiency – accounts for thrust deduction and wake fraction.
- Total propulsive efficiency – overall conversion of fuel energy to motion.
- Engine load factor – actual power as a fraction of rated power.
- Power utilisation factor – proportion of engine capacity used for propulsion.
- Fuel oil consumption reporting – standardized documentation of fuel use.
- EEDI – design-stage CO₂ emission index.
- CII – operational CO₂ intensity metric.
- Wind resistance – aerodynamic drag component.
- Current effect – influence of ocean currents on speed and power.
- Fouling factor – increase in resistance due to marine growth.
- Propeller slip – difference between theoretical and actual propeller advance.
- Thrust deduction factor and wake fraction – hull-propeller interaction coefficients.
- Auxiliary power consumption – fuel used by non-propulsion systems.
- Fuel oil quality – parameters affecting combustion and emissions.
- Calorific value – energy content of fuel.
- Temperature and density correction factors – adjust fuel volume to standard conditions.
- Energy management system – software for real-time performance monitoring.
- KPI – quantifiable performance metrics.
- Benchmarking – comparison against peer vessels.
- Voyage data recorder – source of detailed operational data.
- Weather routing – route optimisation based on forecasts.
- Hull cleaning schedule and coating performance – measures to control fouling.
- Engine condition monitoring – sensors and analysis for health assessment.
- Combustion optimisation – tuning engine parameters for efficiency.
- Emission monitoring – measurement of pollutants.
- Carbon accounting – quantifying greenhouse-gas emissions.
- EEOI – combined fuel, cargo and distance efficiency metric.
- Ship-to-shore data exchange – transmission of performance data to shore.
- Data validation – ensuring accuracy before analysis.

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- Statistical analysis – techniques to extract insights from data.
 - Root-cause analysis – identifying underlying reasons for deviations.
 - Corrective action plan – structured response to performance issues.
 - Continuous improvement cycle – Plan-Do-Check-Act methodology.
 - Operational envelope – permissible operating limits.
 - Speed-fuel and power-speed curves – relationships guiding optimisation.
 - Voyage optimisation – holistic approach to minimise total cost.
 - Fuel surcharge and carbon tax – financial mechanisms linked to fuel use.
 - Regulatory compliance – adherence to international and regional rules.
 - Data archiving – long-term storage of performance records.
 - Stakeholder communication – reporting results to interested parties.