MariEMS Learning Material

This is the 33rd compilation by Professor Dr Reza Ziarati on the work of the EU funded Erasmus + MariEMS' partners and material extracted from the IMO TTT Course. The material is composed from Chapter 33 of the learning material. Readers are also advised to refer to the papers on IdeaPort and IdealShip projects led by C4FF and published by MariFuture.

33. Ship Performance Monitoring and Reporting

33.1 Introduction

In shipping industry, there has been a continuous demand and interest in ship performance monitoring (SPM) overall and also the monitoring of ship's major operations or machinery systems. When high fuel prices and air emissions control take centre stage in the marine industry, the urge to increase a ship's energy efficiency using SPM is normally higher. Additionally, the more sophisticated engines with their recent developments in the combustion process (with thermal efficiencies reaching up to 52%), waste heat recovery systems (with reported benefits of 10% extra energy efficiency), use of emission reduction technologies such as SOx scrubbers and the persistent issues of variable quality fuel; all dictate a closer monitoring on the fuel engine itself, and exhaust system as a matter of best practice. The propulsive (hull and propeller) efficiency can be improved significantly by reducing hull and propeller surface roughness. Frictional resistance forms about 70-90% of the total resistance of a ship for bulk carriers and tankers (approx. 50% for cruise liners and container vessels) and is directly affected by hull roughness, which in turn is affected by fouling. Keeping the hull and propeller smooth and free from fouling is therefore essential for optimal ship energy efficiency.

Hull fouling is affected by type of paints. In the past, hull fouling has been combated by antifouling coatings for example Tributyltin (TBT) that is now regarded as environmentally toxic. The complete ban on TBT in marine antifouling systems by the IMO in 2008 resulted in an increased use of biocide free foul-release coatings. There is not extensive experience on the effectiveness and performance of new paint systems in terms of long-term frictional resistance and fouling in service. The effectiveness of the coatings can be assessed by doing SPM over a long period and comparing speed and power capabilities with clean-hull performance.

As a result of energy efficiency regulations (see Module 2), a large number of energy efficient technologies has been identified that could be used on board ships. However, uncertainty in level of savings due to each technology, and inaccuracies associated with measurement and verification of saving level are major barriers for use of such technologies. An effective SPM would support the uptake of these technologies.

In this section, various aspects of ship performance monitoring (SPM) are discussed. Various methods are proposed and main components of such systems are identified. The analysis methods, practical systems and scope of applications are discussed. The intention is to show that performance monitoring is a key technology for ensuring an effective ship energy management campaign that aims for a reduction in ships' fuel consumption and environmental pollutions.

33.2 Benefits of Ship Performance Monitoring

Knowledge and understanding of a ship's performance and condition in terms of a ship's speed and power, engines' condition, voyage performance, port operation performance, etc. are useful both from economic and environmental points of views. The following overall capabilities and benefits may be attributed to an effective and integrated SPM system [Thijs Willem Frederik Hasselaar]:

- **Assessment of hull condition:** If a proper hull performance analysis system can be developed, it could be an invaluable tool for assessment of hull roughness, hull fouling, the quality of coatings and paints. Also, it could be very effective in determination of the economically optimum intervals for hull cleaning or dry-docking with due consideration for economic penalties and delays due to fouling, etc.
- **Assessment of engine condition:** With a proper engine performance monitoring, the effects of any adjustments in the timing of injection system, valve timing changes or important engine faults such as worn or damaged piston rings, faulty injection, burned valves, fouled turbochargers, air filters, air coolers etc. can be evaluated and diagnosed. Such a system is needed for protection of the engines themselves that are high value costs and safeguards the safety of ships in addition to economics benefit of having the highest engine efficiency possible.
- **Feedback to a better ship design:** When the actual performance of a ship in service is known and the degradation after a number of years is evaluated, the correct service and engine margins can be estimated for definition of design point, definition of ship-propeller-engine matching as well as more informed choice of propeller and engine for future ships.
- **Improved commercial aspects for chartering and technology upgrade:** A more accurate estimate of the ship performance is essential not only for improvement to charter party agreements but also for use of energy efficient ships, and decision making on use of energy efficient technologies. When it is feasible to determine a ship's performance accurately with due consideration to operational environmental and loading conditions, agreements between charterers and ship-owners or technology supplier and owners (for technology upgrade activities) can be defined more precisely.
- **Long term operational optimisation:** When the ships' performance and process parameters are measured simultaneously at frequent intervals and over time, a large database could be organised which facilitates more effective monitoring of a ship's or fleet's performance. Trim, draft, autopilot and engine settings in different environmental conditions are examples of areas that can be optimised. Moreover, with the availability of reliable information of the vessel's sailing performance, the ship's crew would be able to obtain a better understanding of the impact of their actions.
- **Environmental assessment:** As a response to global pressures caused by environmental concerns on ship GHG emissions and the introduction of CO2 indexing schemes such as the IMO Energy Efficiency Operational Indicator [MEPC.1/Circ484] and Ship Energy Efficiency Management Plan [MEPC.203(62) and MEPC.213(63)], and current debate at IMO on data collection system; all in all, the requirements for continuous performance monitoring and benchmarking of fuel consumption, ship energy efficiency and exhaust emissions have increased. An effective SPM will support this process.

33.3 Performance Monitoring System Design

To assess the performance of a ship and provide the benefits outlined above, tools that would provide simple but would provide technically robust results need to be established. In an ideal case, the tool will be a total-ship integrated performance monitoring system that would provide not only an overall performance assessment of the ship but also specific assessment results for the propulsion system, engines, machinery and voyage optimisation. Figure 33.3.1 shows the basic concept of a ship performance monitoring system.

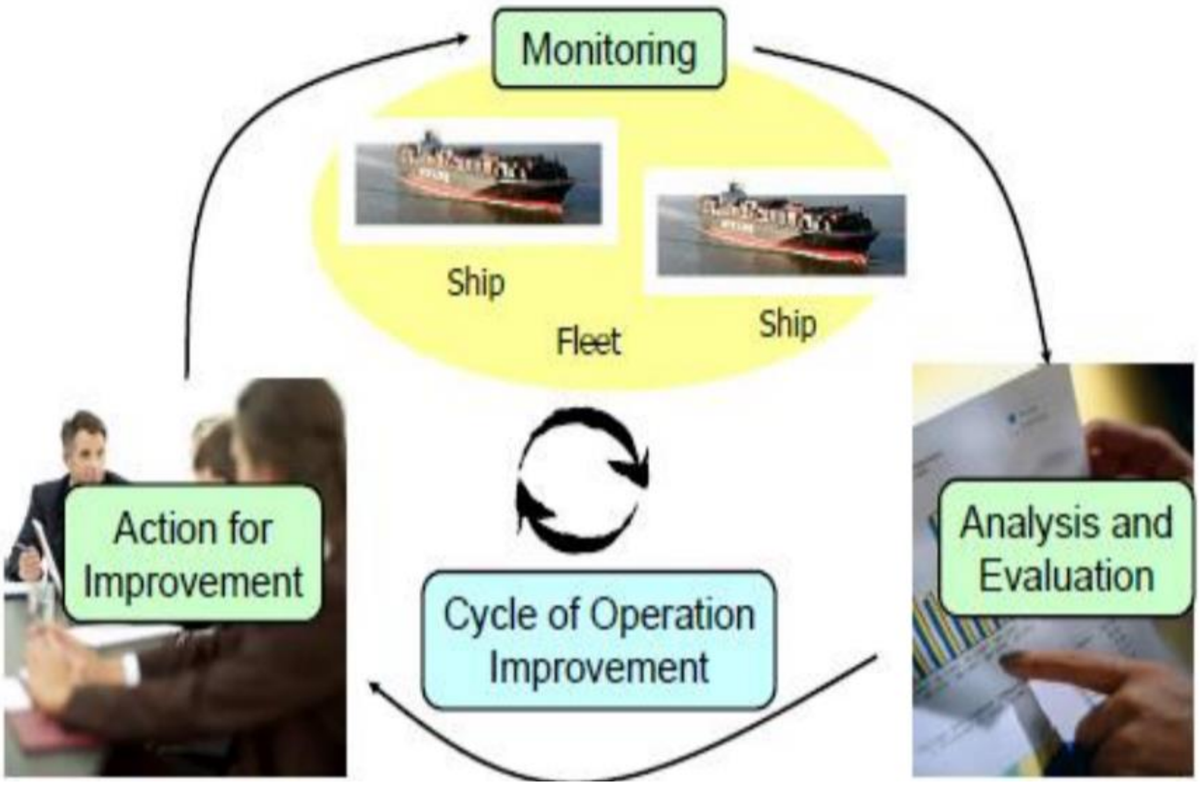

Figure 33.3.1 – The general concept for a ship performance monitoring [Hideyuki Ando, NYK]

At the heart of a ship performance monitoring system is the data gathering, data analysis and data presentation aspects. This is conceptually shown in Figure 33.3.2.

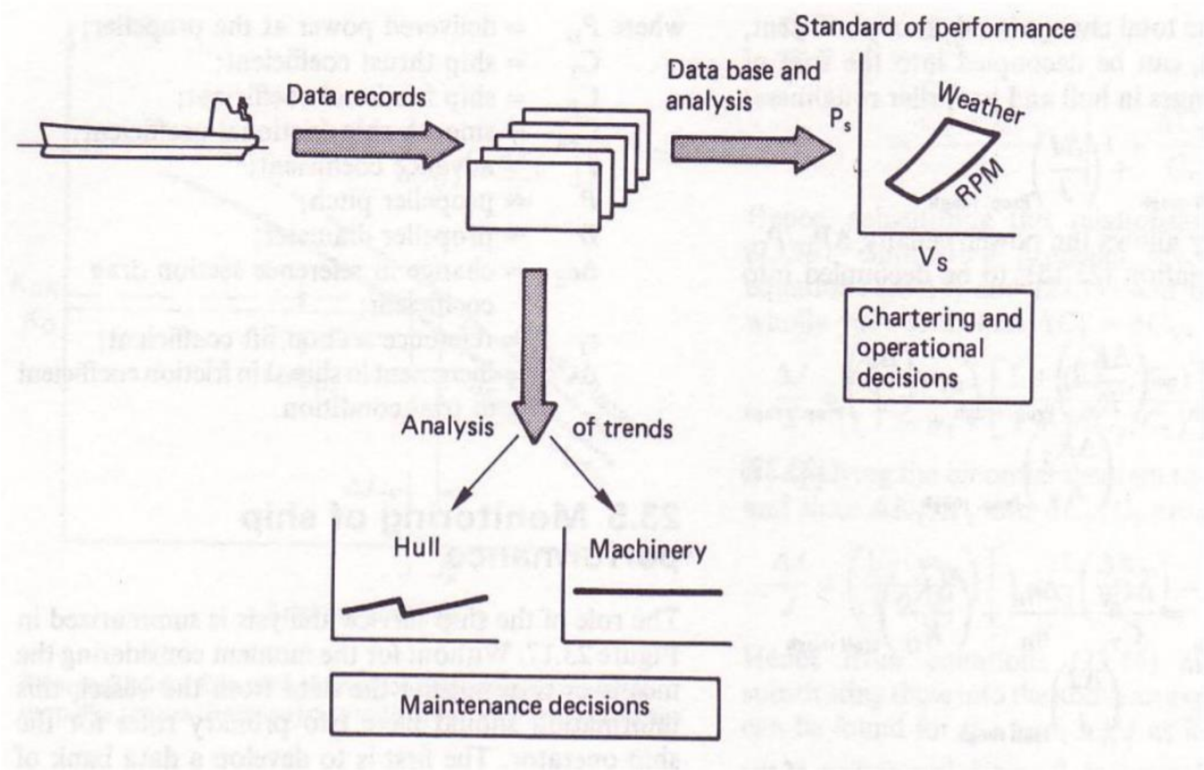

Figure 33.3.2 – Performance monitoring data collection, analysis and presentation concepts

A SPM, depending on its design and purpose, could provide various functionalities. Generally, a SPM may include modules that provide capabilities in performance monitoring of the below aspects of a ship:

- Ship voyage and operation
- Hull and propeller
- Engines
- Auxiliary machinery
- Etc.

For an integrated performance monitoring system, detail information by using automatic data collection and analysis are necessary. There is a need to go through feedback loops for operation performance improvement as indicated in Figure 33.3.1. The combined system, especially the combination between voyage performance, weather routing and performance monitoring is important. An integrated SPM provides organisational improvement process for energy efficient fleet operation that is in-line with IMO activities with regard to SEEMP, EEOI and future data collection and reporting.

The issue of design and development of such a system is out of scope of this section; suffice to say that a good design for a condition or performance monitoring will include [Hideyuki Ando, NYK]:

- Interface to existing on-board equipment and data systems is essential as already most of the required data are measured on-board ships.
- Automatic data processing and transferring to shore.
- Least additional work load on crews.

- High reliability and 24/7 operation.
- Low cost of implementation.
- Flexibility of customization to existing ship-board systems.

33.4 Types of Performance Monitoring Systems

Broadly speaking, the SPMs can fall into the following three main categories based on their method of data collection and analysis:

- Manual: Systems with manual data logging, data analysis and reporting (for example once every 24 hours)
- Automatic: Systems with automatic data logging, data analysis and reporting (sampling can be every 1 sec or above and analysis can be either scheduled, continuous or on demand).
- Hybrid: Hybrid systems with some manual and automatic elements.

In practice, most of the systems are of hybrid nature with some elements of manual data logging or actions on data. Some are significantly on the manual side and some are significantly on the automatic side.

33.4.1 Manual systems

The manual systems normally rely on data that are gathered manually from various measurement devices or logbooks. On-board most merchant ships, daily logbooks are used to record the engine, fuel, navigation and cargo parameters for monitoring and regulatory purposes. Engine-logs are mainly of interest for engine maintenance and provide technical data to assess the condition of the engine and machinery. Deck- or navigation logbooks are used for voyage planning, insurance/safety and ship handling analysis, while loading logbooks are used for stability assessment, cargo planning etc. Additionally, there is significant additional ship-board information such as fuel oil analysis records, engine condition analysis records, etc. that could be utilised.

Engine and deck logbooks are traditionally filled-in either once a day (noon-noon logs) or every watch (4 hours) and averaged over 24 hours to form ‘log abstract’. The number of variables that are logged depends on the requirements from the shipping company, the available instrumentation and the motivation and training of the crew [Thijs Willem Frederik Hasselaar]. A typical deck log contains information about the ship’s position, speed, propeller revolutions, slip, draft, and sea state. A typical engine log book will include engine-related data such as power, rpm, temperatures, fuel oil consumption, etc.

Because logbooks are used on all ships, they are often used for performance and condition monitoring; primarily by the chief engineers. Their wider application for ship performance monitoring is limited since ship performance monitoring requires a higher level of data resolution and accuracy than what logbooks can provide. Also, the details in the logbook are average values for a long period of time (e.g. 24 hours) that hides some of issues from observation. The following shortcomings of manual data logging can be named [Thijs Willem Frederik Hasselaar]:

- Uncertainty in the used instrumentation. To increase redundancy, critical sensors for ship performance are often duplicated. Experience indicates however that duplicate instruments often show differences. Unless well described, this causes confusion in which instrument indicates the best true representation and should be used for performance monitoring.

Furthermore if the source of the instrument is unknown, the reliability of the logged data is low.

- Wrong data collection timing: A time lag of an hour in sampled data may represent two completely different performance conditions if environmental or sailing conditions have changed in this period. Most parameters, such as torque, are affected by even the smallest change in environment, and require therefore that all parameters are logged at the same time
- Insufficient training: If parameters cannot be measured using dedicated instruments, for example for measurement of sea wave characteristics, visual observations must be made. They can be accurate, if done by highly experienced officers, but change of shifts and quick changing vessel crew causes inconsistent observations.
- Inaccurate data collection: Certain parameters (wind, speed, torque etc.) must be averaged over a time period to be meaningful. Spot measurements result in errors. Furthermore, it is normal practice for officers to enter higher sea states than actually experienced in order to cover the vessel if delays are experienced (due to engine problems, strong currents, course alterations etc.). This may be done to avoid claims from the charterer on the level of a vessel's capabilities.
- Limited logging frequency: The high workload of the officers on duty limits the logging frequency for performance monitoring. With the recent increase in regulations, the number of administrative tasks and safety checks has increased dramatically with many officers complaining that there is little time left for watch keeping and optimal ship operation.
- Errors in data entry: Experience indicates that abstract logbooks frequently contain data inconsistencies, e.g. wind, water and ground speeds are mixed up, unrealistically high or low parameters are entered or relative wind instead of true wind speed is logged. The errors may be the result of unclear logging protocols, inaccurate sensors or insufficient training. In such cases, error tracking is difficult.

On the positive side, with the developments in satellite communication, internet and email, electronic logbooks have emerged and are used more and more. They replace paper abstract logbooks and enable logs to be send via email or web to shore, allowing ship performance to be analysed on a daily basis. Furthermore, with electronic communications, it is easier to identify anomalies directly at source and, if applicable, daily feedback of the ship's operation can be send back to the vessel. The data however still represents manual spot measurements with relevant key weaknesses.

33.4.2 Automatic system

With the introduction of electronic remote measurement and wireless data transmission from ships, it is now possible to collect many ship performance parameters electronically. A central data acquisition system interconnected to all necessary instrumentation can monitor and store data for either instantaneous or offline analysis (see Figure 33.4.2 for the concept).

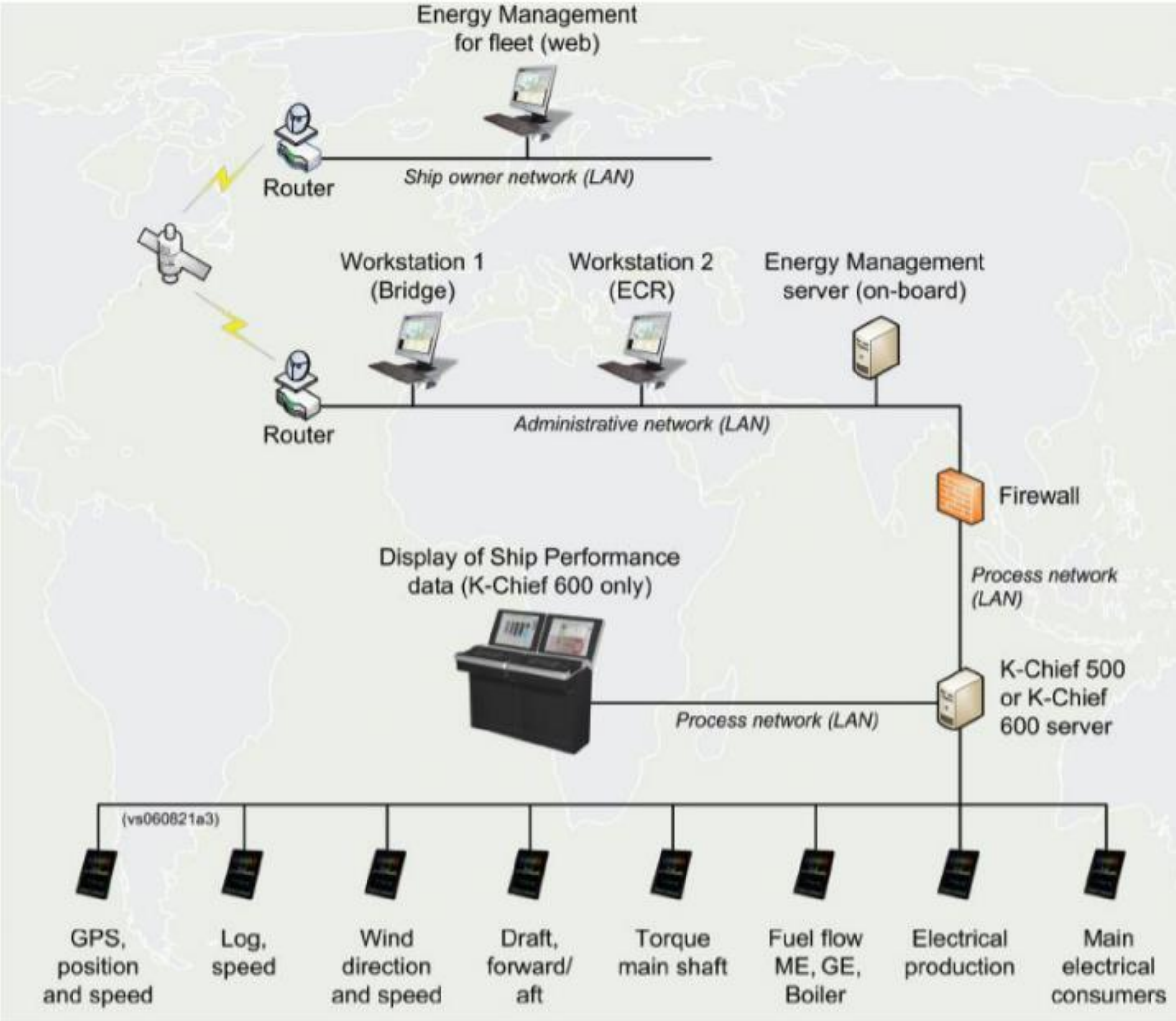

Figure 33.4.2 – Automatic systems using satellite navigation [Kongsberg]

The automation of data collection has the following advantages:

- Contributes significantly to the improvement of data quality.
- Allows signal validation, filtering and averaging for increased accuracy and reliability
- The source and characteristics of each sensor can be described and documented accurately, which reduces the uncertainty and errors in data entry
- Automatic data collection allows real-time data analysis, which can be used for monitoring for alarm in extreme operating conditions or real time feedback on vessel operation.

An example of automatic data logging systems is a ship's Voyage Data Recorders (VDR). A VDR is an automatic data logging system for accident investigation collecting information concerning the position, speed, physical status, command and control of a vessel over the period leading up to and following an incident [Thijs Willem Frederik Hasselaar]. Based on IMO regulations, use of VDR (that is like a black box) is mandated on certain ship types and sizes. Many parameters logged by a VDR are required for performance monitoring. The use of the VDR data for performance monitoring is not advocated here; however, an automatic performance monitoring system will provide similar type of data collection functionality.

33.5 Hull Performance Monitoring

33.5.1 Introduction

It is well known that ship resistance increases with service life. Figure 33.5.1.1 shows the ship resistance caused by degraded hull and propeller conditions, at design draft and design speed, as a percentage of the total ship resistance “as-new”.

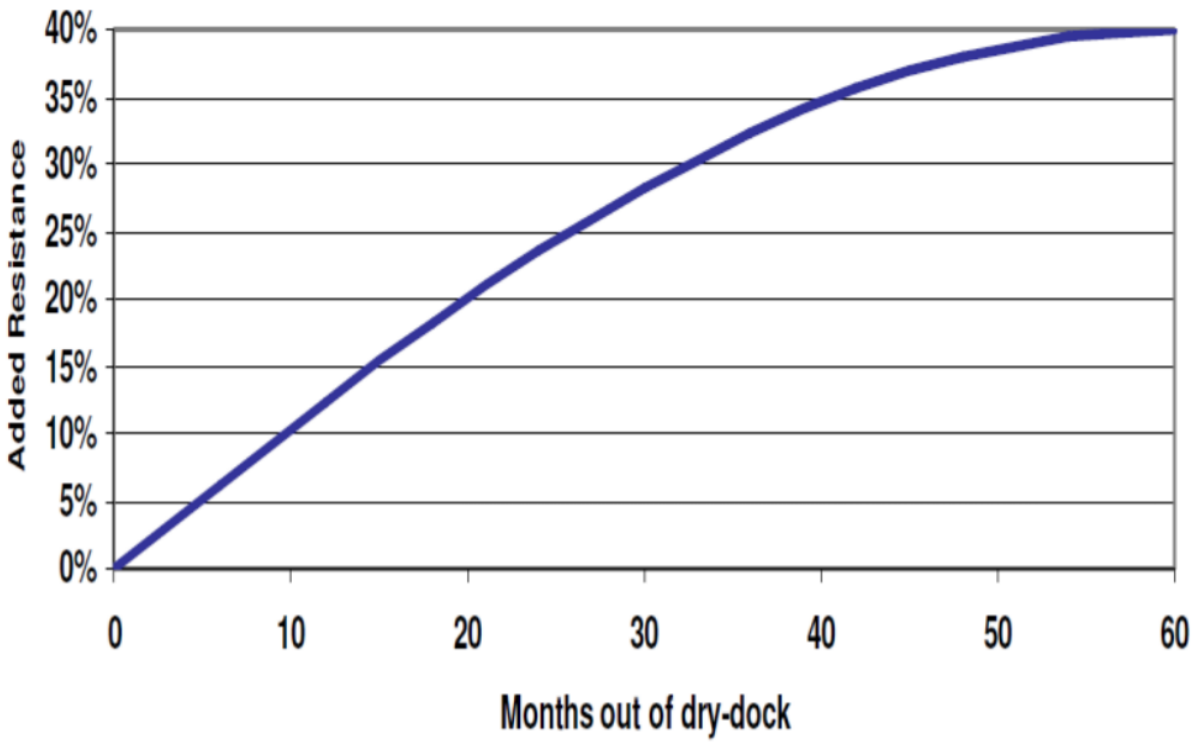

Figure 33.5.1.1 – Development of added resistance normally expected as a function of time [Torben Munk]

The addition of added resistance would lead to higher power required from the propulsion engine and thus higher fuel consumption. Typical increases reported is shown in Figure 33.5.2 as example that indicates reduction of fuel consumption before and after hull brushing and cleaning.

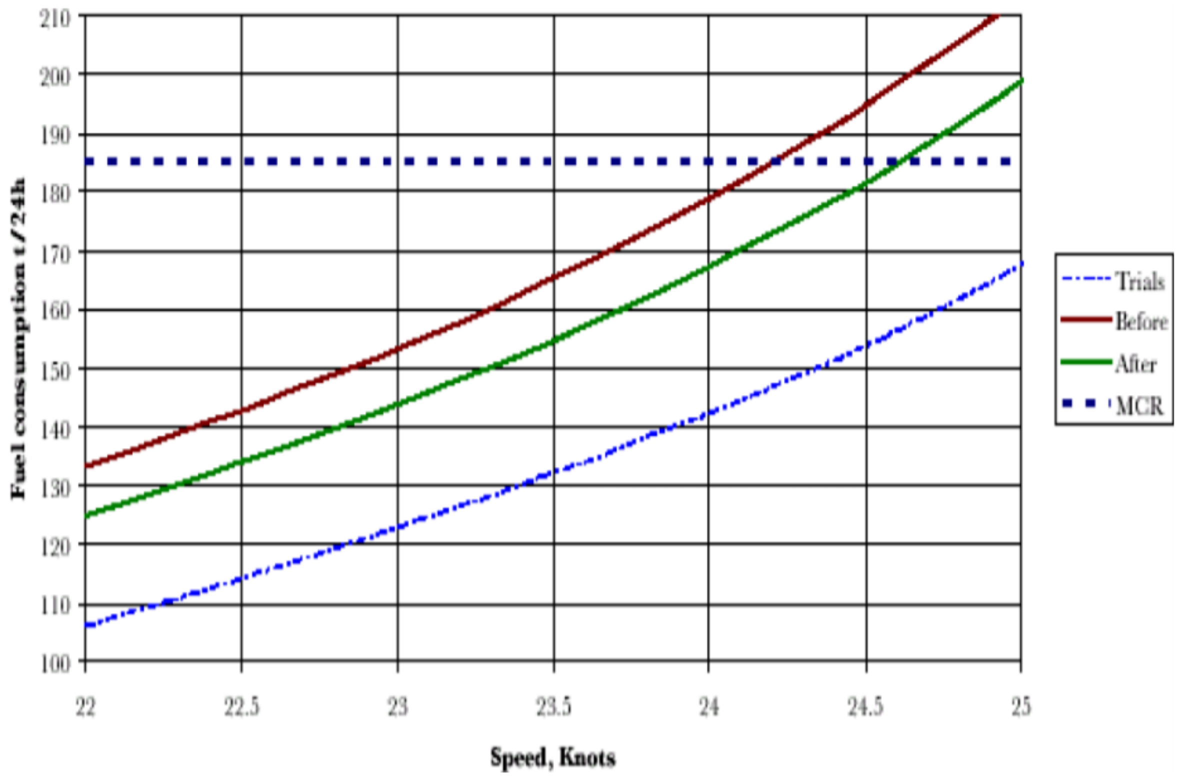

Figure 33.5.1.2 - Fuel consumption penalty of hull fouling and benefits of condition-based cleaning [Torben Munk]

Based on the above, the need to justify the importance of assessment of hull and ensuring that it remains clean during ship operation is self-evident. The main question to be answered is how the monitoring can be done and if current technologies and systems are effective.

33.5.2 Methodology

A variety of methods have been proposed for assessment of hull surface condition including:

- Assessment of ship speed-power curve relative to a baseline.
- Assessment of level of added resistance relative to a baseline (e.g. Figure 33.5.2)
- Use of divers to visually inspect the hull and propeller conditions and decide on the best course of action.
- Etc.

As an example, the 1st methodology above is described here. To monitor the propulsion performance of the vessel, a reliable and accurate speed – power curve should be developed. This curve should then be compared to its counterpart as developed under commissioning speed trial (as baseline) to evaluate deviations from base line conditions. To enable this process the following data should be collected under a number of ship speeds (to cover full range of ship speed):

- Propulsion data
  - Propulsion shaft power and rpm
  - Ship speed both over ground and through water
  - Main engine fuel consumption and relevant properties.

- Environmental conditions
  - Wind (speed, direction, etc.)
  - Sea state (wave force, direction, etc.)
  - Etc.

The above list is only a guide and need to be more detailed for data collection purposes. Additionally, and for analysis purposes, some of the hull and superstructure data and ambient pressure and temperature will also generally be needed.

To collect the required data, ideally, the actual tests should be done in a way that the impact of sea currents is eliminated (using double run tests where the ship is sailed in opposite direction and then results are averaged). However, in practice, this is not commercially feasible; thus trials under clam sea conditions in areas with little currents are recommended.

To determine the actual speed – power performance of the ship in a changing ambient conditions an analysis method is required. To be effective, this method should eliminate the effect of wind and waves. Currently, evaluation of hull fouling is difficult due to unavailability of proper environmental correction methods.

Based on this methodology, ship speed power curves can be developed as show in in Figure 33.5.2.1

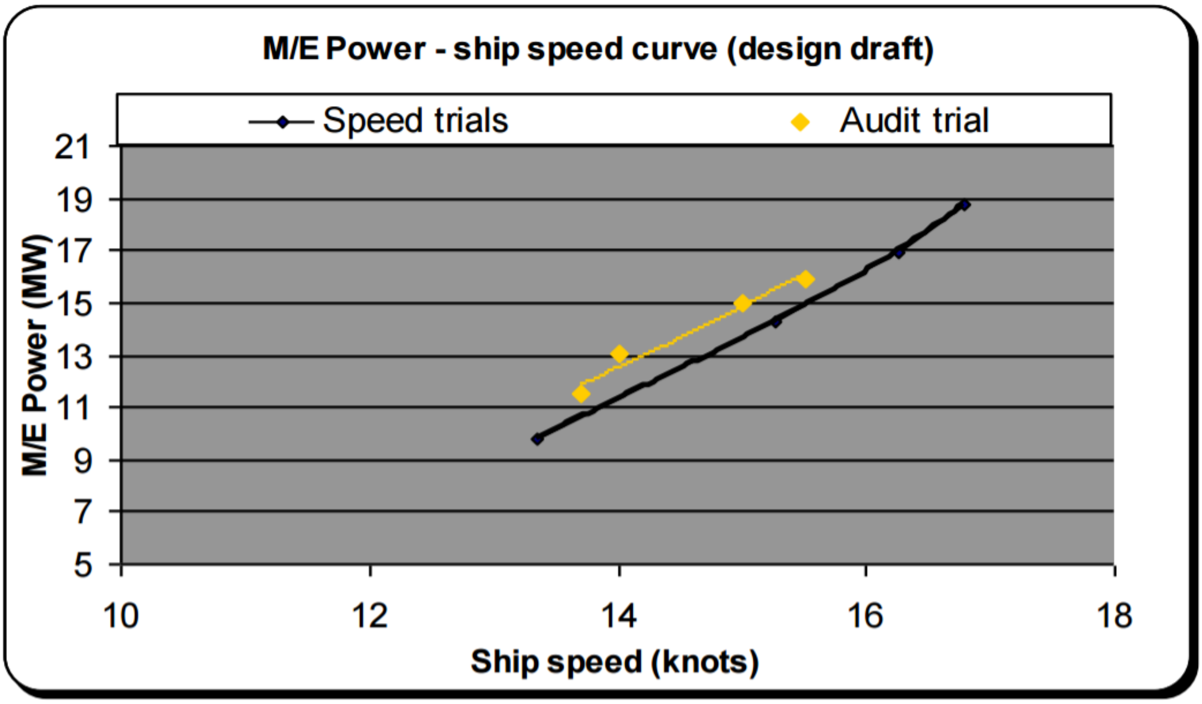

Figure 33.5.2.1 – Example of speed-power curve development [Bazari 2012]

This method is highly influenced by ship's ambient conditions; and data correction methods are still evolving. However, the use of this technique has been successful when tests are done under controlled conditions, well-defined test procedure and good sea conditions. Propulsion Dynamics (http://www.propulsiondynamics.com/our-service.html) uses the notion of added resistance for their performance monitoring services. Figure 33.5.2.1 shows example of their results and the way they predict hull fouling.

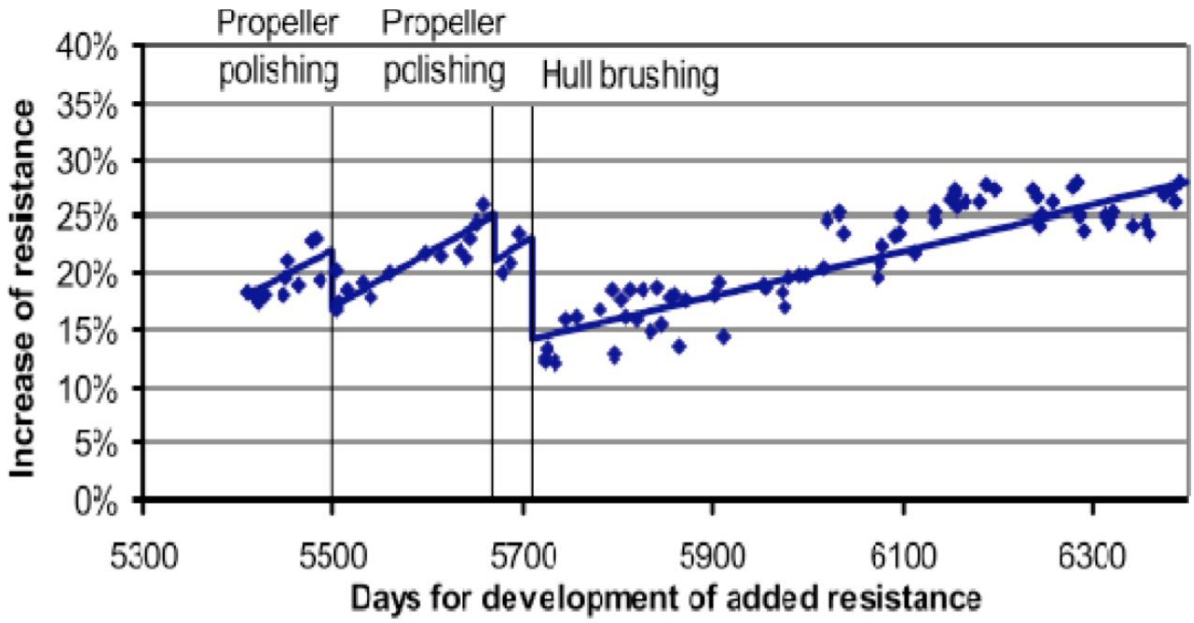

Figure 33.5.2.1 – Added resistance method used by Propulsion Dynamics [Torben Munk]

33.6 Engine Performance Monitoring

33.6.1 Introduction

The main purpose of a diesel engine performance monitoring system can be defined as "the monitoring, indication and subsequent assessment of the operational efficiency and performance levels of the diesel propulsion engine and its respective subsystems". The objectives of this form of performance monitoring are:

- To facilitate the efficient, economic and optimal operation of the diesel engines.
- To reduce the possibility of "off design" operation that generally leads to degradation of both the individual components and the overall system reliability and service life.

Diesel condition monitoring has longer history of application in marine diesel engines. It is regarded as "the monitoring of component or system wear and degradation in order to predict scheduled maintenance or at least to avoid catastrophic failure". When dealing with condition monitoring, a number of techniques are normally used such as:

- Vibration monitoring
- Thermography monitoring
- Lube oil monitoring
- Performance process monitoring

Referring to the definition of performance monitoring, the last item of condition monitoring on "process parameter monitoring" closely ties up with performance monitoring. While in condition monitoring, the aim is to identify degradation in order to prevent failures and improve maintenance, in performance monitoring the constant strive is for economic or environmental efficiency of the system; thus it goes beyond simple condition monitoring or maintenance management.

It is important to note that when a process parameter monitoring system is to be applied, the success rate is determined by choosing the right parameters to monitor, select accurate sensors and signal processing systems and implement the output of the processing system.

33.6.2 Methodology

Engine performance monitoring mainly relies on monitoring of engine's in-cylinder conditions in particular the cylinder pressure diagram (or "indicator diagram" as commonly known historically). A very good indication of engine health as well as its energy efficiency is the maximum cylinder pressure. Lower than expected cylinder pressure generally means that engine settings are not optimal or its components may be faulty. Thus, use of measured cylinder pressure data forms the core of engine performance monitoring systems (as well as condition monitoring systems). Figure 33.6.2.1 shows a typical cylinder pressure diagram, with important characterising parameters marked on it.

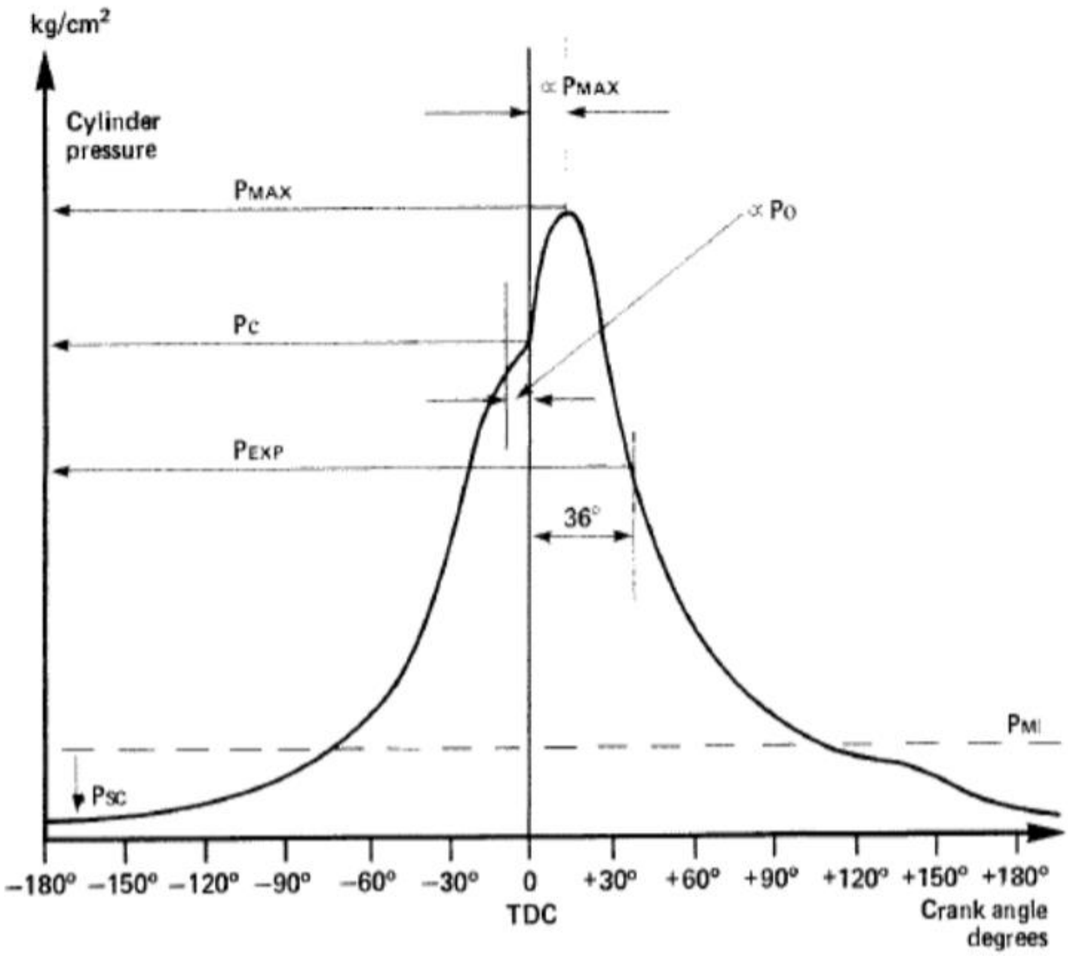

Figure 33.6.2.1 - Typical engine indicator diagram

The above diagrams can be measured digitally/electronically these days on the majority of commercial vessels (this is normally done on a monthly basis). Using the measured diagram as above, the following information can be extracted (automatically):

- Maximum cylinder pressure (Pmax)

- Angle of Pmax– The angle at which Pmax occurs.
- Cylinder compression pressure (Pcom) – Pressure when piston is at Top Dead Centre position.
- Ignition angle – The angle at which combustion starts.
- Indicated power - Engine power as measured on top of the piston. Due to mechanical frictional losses, this indicated power is higher than the brake power that is measured at output shaft of the engine.
- Etc.

In addition to cylinder pressure diagrams, current day systems collect other data such as:

- Engine rpm
- Engine brake power
- Scavenge pressure
- Fuel injection pressure diagram and relevant information such as injection timing.
- Turbocharger rpm
- Etc.

Following the measurement of the above process data, they need to be corrected, if applicable, and compared to benchmark levels to identify if they are within the acceptable range. The benchmarks are normally extracted from the engine shop test data. The engines' shop test results are generally measured and corrected for standard environmental conditions. Therefore to enable comparison of measured values against earlier corrected results, the parameters may need to be corrected to shop trial conditions. To calculate the engine's BSFC (Brake Specific Fuel Consumption), a correction for the density and heating value of the fuel will be required.

When the data have been collected and corrected, the relevant graphs are constructed in order to monitor and evaluate the engine's condition and performance. The following comparisons could form the basis for performance deviation diagnostic purposes:

Cylinder pressure: Low maximum combustion pressure relative to baseline is indicative of retarded injection timing or low scavenge pressure, provided that injectors, valves and rings conditions are evaluated as satisfactory.

Turbocharger speed: Higher turbocharger speed relative to reference data will indicate that engine settings may not be optimised. A high turbocharger speed may indicate the following:

- A retard injection with more energy going to exhaust rather than conversion to work in cylinder.
- A fouled turbine casing that may result in slightly higher engine back pressure.

Exhaust gas temperature: A higher than normal exhaust gas temperature could be due to few reasons such as high ambient temperature and high scavenge temperature (possibly due to charge cooling issues) or a retarded injection. Figure 33.6.2.2 shows a sample of cylinder pressures monitored, showing anomaly with one of the cylinders (red line).

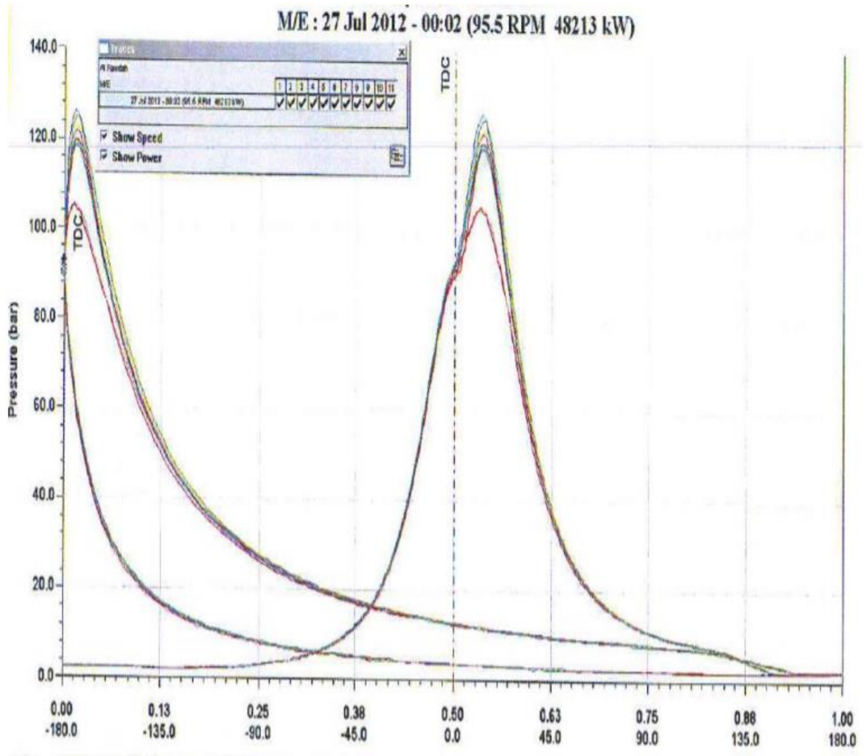

Figure 33.6.2.2 – Typical on-board in-cylinder measurement [Bazari 2012]

33.7 Auxiliary Machinery Monitoring

The monitoring of auxiliary machinery may be carried out in a variety of ways. For energy efficiency purposes, one way is to monitor the level of utilisation of machinery that is represented by their run hours. This will demonstrate if the ship’s redundant parallel machineries are used too much beyond requirements. This is done via evaluation of utilisation factor and their comparison to benchmark values.

Figure 33.7.1 shows an example of such an analysis for a number of auxiliary machinery; where the actual and reference utilisation factor for some major energy consuming machinery are shown.

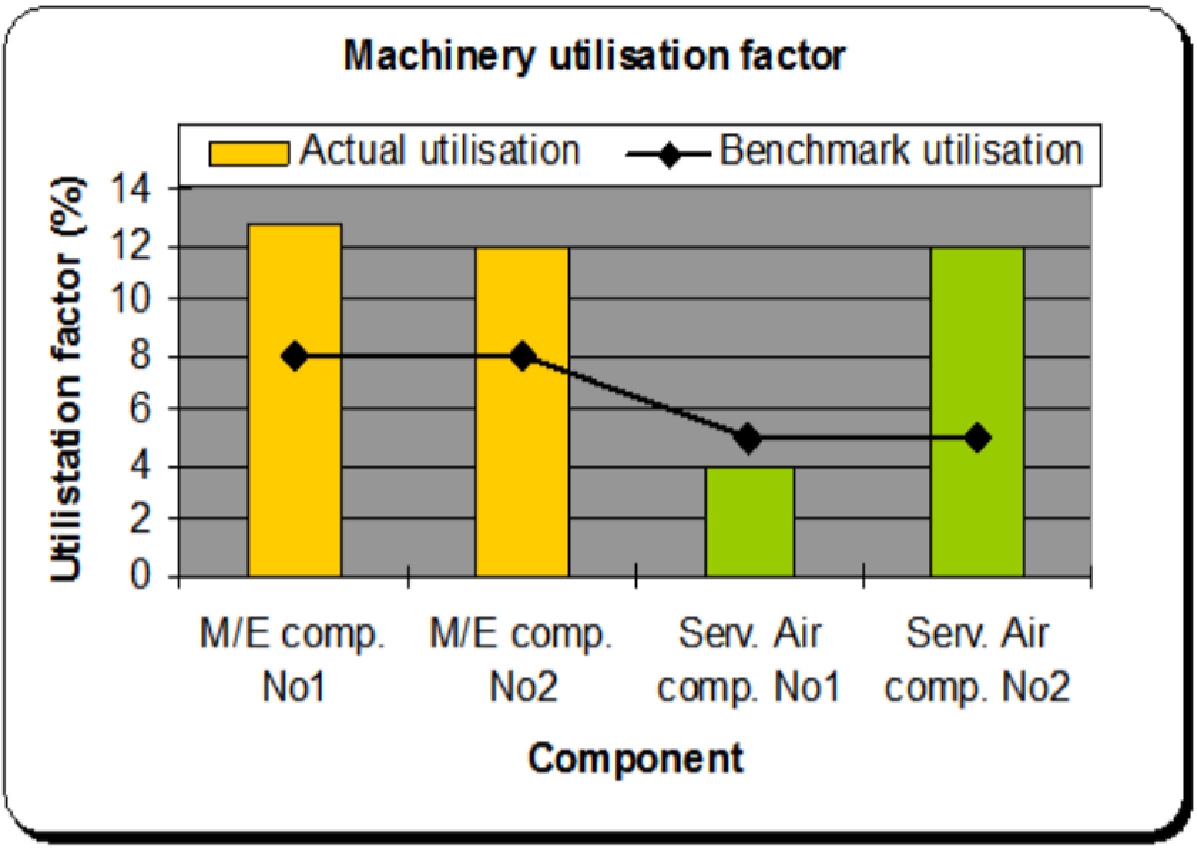

Figure 33.7.1 - Machinery utilisation [Bazari 2012]

Presentation of the above data over time will ensure optimisation and reduction of ship's auxiliary machinery run hours that would lead to not only lower energy use but less need for maintenance.

33.8 Voyage Performance Analysis

To improve the ship's itinerary and voyage management, a rigorous process that examines all aspects of the ship's operations needs to be in place. Data that could be used to evaluate the ship's operations should be collected and compared against developed benchmarks/baselines. The important data elements for voyage analysis will include analysis of ship operation events and their time durations (e.g. cargo loading, cargo unloading, port waiting, port berth times, passage operation, etc.).

To acquire such data, a computerised system will be required. However, such data are also available manually from deck logbooks as well as port reports that are available on-board ships. Additionally, full and continuous recording capability of voyage information as shown in Figure 33.8.1, inclusive of detailed propulsion system data, would support to optimise voyage operational performance.

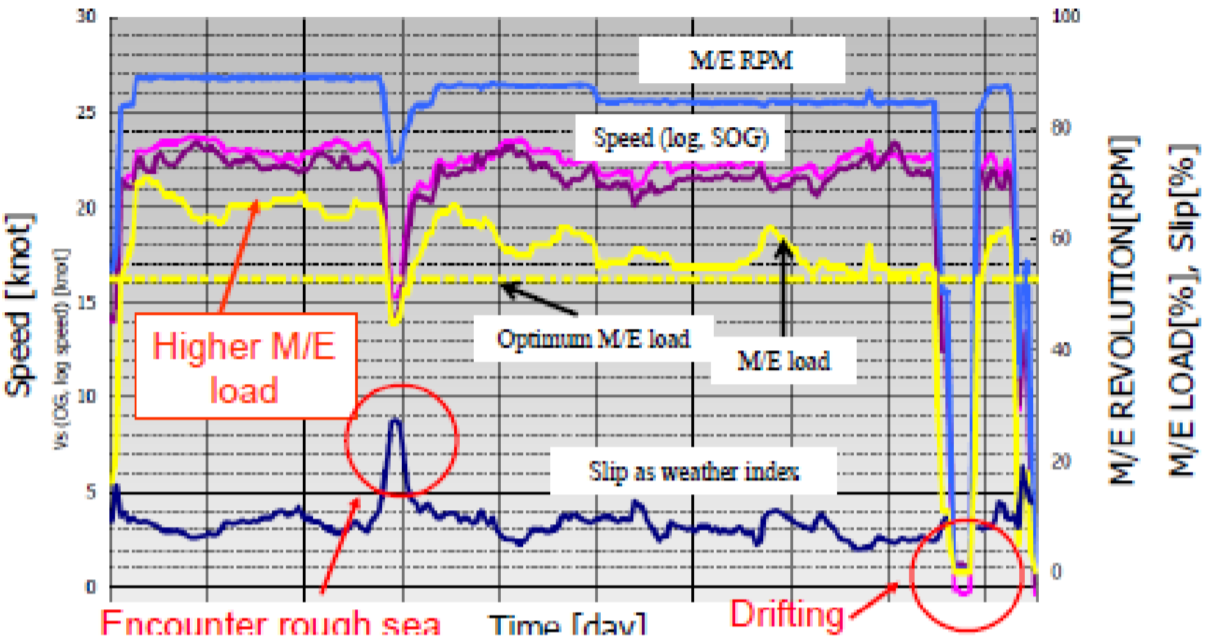

Figure 33.8.1 - Overview of a ship operation from one port to next port using performance monitoring [Hideyuki Ando, NYK]

For voyage performance analysis, these days, the weather routing service providers offer voyage performance analysis. In such a case, comparison between voyage plan and actual including ship performance (rpm, speed, fuel consumption) as a function of weather condition (wind and ship motion) are estimated and compared.

33.9 Monitoring and Reporting to External Bodies

The other aspect of energy performance monitoring mainly relates to obligation of the company to report to external stakeholders. The stakeholders could be the commercial clients or shippers or could be regulatory authorities. On the regulatory authority side, two initiatives are important for further consideration:

- IMO data collection system
- EU MRV (Monitoring and Reporting and Verification)

The above are further described in this section.

33.9.1 IMO data collection system

IMO MEPC Working Group on “further energy efficiency measures” has been working on the subject for some time and still continuing this work at the time of writing these texts. The approach advocates “data collection” as applied to ship fuel consumption and possibly other parameters. The system will have three main elements: (1) Data collection by ships (2) Flag State functions (data verification and submission) and (3) Establishment of a centralised database by the IMO and annual submissions.

The regulatory aspects of the IMO data collection and reporting system was introduced in Module 1 together with progress so far in its development and adoption. The reader should refer to module 1 for details; however the main features of the scheme are summarily mentioned below as:

- It will be applicable to ships greater than 5000 GT.

- The reporting period will be annually with no need for voyage data declaration.
- IMO number for ship will be part of the data for ship identification purposes.
- Ship's registered owner will be responsible for submission of data to Administration. Responsibility of reporting remains with the ship.
- Flag Administration will be responsible for verification of the data; this can be delegated to Recognized Organizations (e.g. Class Societies).
- A Statement of Compliance (SOC) will be issued to the ship annually.
- Port State Control will examine the validity of SOC for enforcement.

Main aspects that have yet to be decided by the IMO MEPC in its future meetings are:

- Confidentiality of the data and who will have access to collected data.
- Guidelines will be developed to deal with various aspects of relevant regulations detailing main features of data collection method and data verification.
- The need for transport work data or energy efficiency indicator and other relevant data has yet to be debated and decided.

33.9.2 EU MRV

EU has for long worked as an advocate of reducing GHG emissions from international shipping. Because of this, EU not only supported the IMO regulatory developments but also has kept one step ahead in pushing forward the GHG reduction agenda. Generally, the EU plan of action is a phased approach to regulating CO_2 emissions as follows:

- Phase 1: Establish an agreed global energy efficiency standard as part of the IMO regulatory framework.
- Phase 2: Implement an MRV scheme to establish the fuel consumption and CO_2 emissions from international shipping, preferably within the IMO framework.
- Phase 3: Identify whether the efficiency standards are achieving the EU's desired absolute CO_2 emissions reductions from shipping, and if not, determine what else should be done, e.g. introduction of a Market Based Measure (MBM).

Phase 1 has already been accomplished and is in place in the form of IMO energy efficiency regulations for ships. It is phase 2 that is the subject of the IMO data collection system and EU-MRV. EU for some time have advocated that any plan to reduce shipping CO_2 emissions in the long term would have to be based on representative and accurate data on shipping fuel consumption and GHG emissions inventories. Within EU MRV, a reporting system is regulated that is going to provide such data. In effect, EU has developed and adopted its MRV legislation force certain ships to report their fuel consumption, energy efficiency performance and related data.

The EU MRV will be described in some detail in the following texts. Lloyd's Register in its summary publication in May 2015 entitled "European Union Regulation on Monitoring, Reporting and Verification of Carbon Dioxide from Ships" provides a succinct but comprehensive introduction to the EU MRV. The material in this section is mainly taken from this publication with some amendments; this is acknowledged here.

Applicability

EU legislation for the EU-MRV regulations was approved by the European Council in 29 April 2015 via amending the Directive 2009/16/EC [Regulation (EU) 2015/757]. Accordingly, the EU-MRV will be implemented in the EU regions and the ships that operate solely in this region or those travelling in and out of the region. The system will work according to the following:

- Irrespective of flag, the regulation applies to ships greater than 5,000 GT (with some exceptions10) undertaking one or more voyages into, out of and between EU ports.
- It requires per-voyage and annual monitoring of CO_2 emissions, as well as other parameters including energy efficiency indicators and amount of cargo carried.
- Annually, shipping companies must provide an emissions report for the previous calendar year's activity. In addition, this will include the technical efficiency of the ship for example in the form of its EEDI.
- Ships are exempted from the obligation to monitor this information on a per-voyage basis if they undertake more than 300 voyages within the reporting period or if all their voyages during the period either start or end at a port under the jurisdiction of an EU member state.

Implementation schedule

The following timescales have been set as part of the regulation for its implementation:

- Preparation and adoption of supporting technical legislation in 2015/2016 including broad stakeholder and expert involvement.
- Accreditation of verifiers in 2017.
- 31st August 2017 – Monitoring plan for each ship to be prepared and submitted for approval by an accredited verifier.
- 1st January 2018 – Commence per-voyage and annual monitoring by applicable ships.
- 2019 onwards – By 30th April each year, submit a verified emission report to the EC and relevant flag State
- 30th June 2019 onwards – Ships will need to carry a valid Document of Compliance (DOC) relating to the relevant reporting period.
- 30th June each year – The EC will make each ship's emissions reports publicly available including information specific to that ship, its fuel consumption, CO2 emissions, technical efficiency (e.g. EEDI) along with other parameters.

Data collection

Each company will be required to produce a monitoring plan which will be used to monitor data on a per-voyage basis. This data will be aggregated annually and reported for all voyages conducted into, out of and between EU ports. The differing requirements for monitoring and reporting on a per voyage basis and on a yearly basis are shown in Table 33.9.2.1.

Annual reporting requirements	**Per voyage reporting requirements**
Aggregated annual CO_2 emissions from all voyages between, from and to ports under a Member State's jurisdiction during the reporting period	Port of departure and arrival including the date and times in and out.
Aggregated annual CO_2 emissions from all voyages between, from and to ports under a Member State's jurisdiction during the reporting period	
Details of the method used for emissions monitoring	
Technical efficiency of the ship (EEDI or EIV as applicable)	
Vessel identification	
Total annual amount/weight of cargo carried	
Annual average efficiency (e.g. EEOI, fuel consumption per distance and cargo carried)	
Total annual fuel consumption	
Total CO_2 emitted	CO_2 emitted
Total distance travelled	Distance travelled
Total time spent at sea and at berth	Time spent at sea

Table 33.9.2.1 – EU MRV monitoring requirements [Lloyd's Register 2015]

CO_2 emissions measurement

The most critical data in Table 33.9.2.1 is CO2 emissions measurement and reporting. The overall EU MRV processes are shown in Figure 33.9.2.2 schematically.

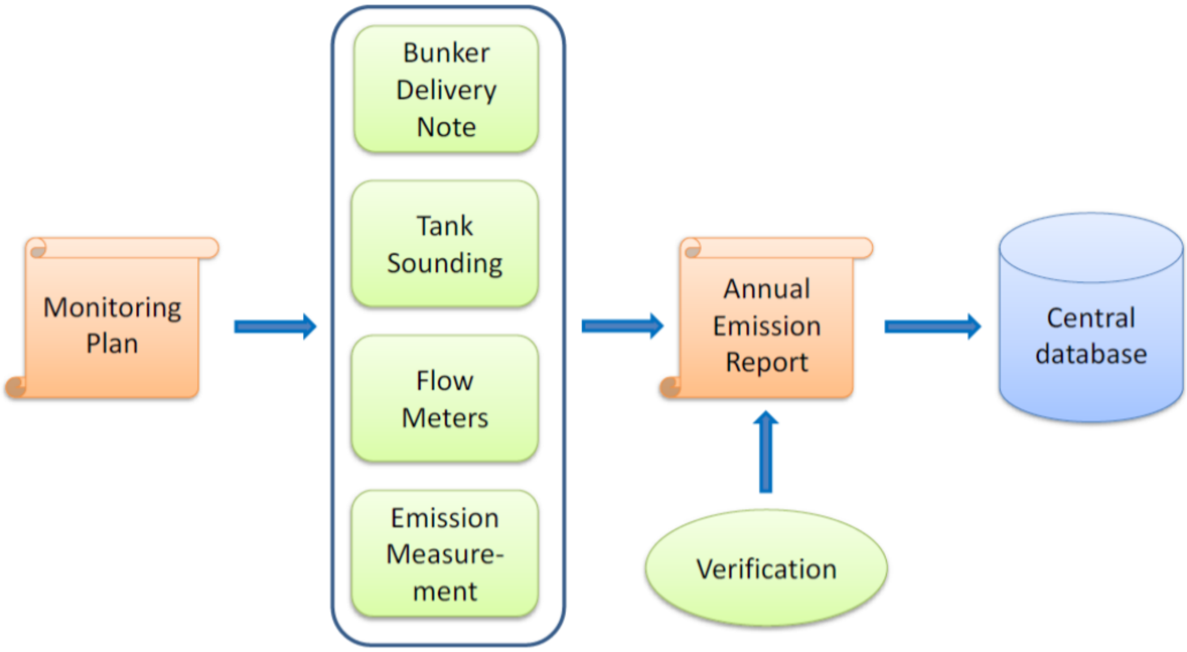

Figure 33.9.2.2 – MRV scheme overview [Lloyd's Register 2015]

As indicated in Figure 33.9.2.2, CO_2 emissions will be calculated based on:

- Either fuel consumption measurement (by (1) bunker delivery notes or (2) use of tank sounding or (3) use of fuel flow meters) and use of appropriate fuel related CO2 emission factor for the fuel type being consumed,

- Or by direct emissions monitoring/measurement, with a back-calculation of the fuel consumption using the relevant emissions factor.

The above options are detailed in Annex I of the EU Directive [Regulation (EU) 2015/757]. As part of the monitoring plan, companies will be able to choose one or more of four methods shown in Figure 33.9.2.2 for CO_2 calculations. Use of a combination of these methods is also permitted if it would improve the accuracy of the CO_2 emission measurement.

The EU MRV regulations also refer to energy efficiency as part of the monitoring and reporting requirements, including 'transport efficiency' and 'average energy efficiency'. These are defined within the Annex II to the EU Directive [Regulation (EU) 2015/757] and have similarities to the methodology for calculating the IMO's Energy Efficiency Operational Indicator (EEOI).

Verification

Tasks related to the check of monitoring plans, emission reports, communication with ship owners and operators and the issuance of Document of Compliance (DOC) will be done by accredited third party verifiers which most likely include classification societies. The EU Directive [Regulation (EU) 2015/757] sets out guidance on the requirements for verification and the main such requirements are summarised as follows:

- Verifying conformity of the monitoring plan against the requirements laid out in the regulation;
- Verifying conformity of the emission report with the requirements laid out in the regulation and issuance of verification report;
- Ensure that emissions and other climate-related data have been determined in accordance with the monitoring plan;
- Determining and making recommendations for improvement to the monitoring plan.

Certification

Upon satisfactory verification of the emission report, the verifier will then issue a Document of Compliance (DOC) to the company. The EU MRV regulations will not be a flag State requirement; instead it will be enforced through Port State Control within European ports.

33.10 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. IMO MEPC.1 Circ.684, "Guidelines for voluntary use of the ship energy efficiency operational indicator (EEOI)", 17 August 2009.
2. IMO, MEPC Resolution MEPC.203(62) "Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978" relating thereto (Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI)", Adopted on 15 July 2011.
3. IMO MEPC Resolution MEPC.213 (63), "2012 Guidelines for the development of a ship energy efficiency management plan (SEEMP)" Adopted on 2 March 2012

4. Hideyuki Ando (NYK Group), "Performance Monitoring and Analysis for Operational Improvements", International Conference on Ship Efficiency Conference, September 2011, Hamburg
5. Thijs Willem Frederik Hasselaar, "An investigation into the development of an advanced ship performance monitoring and analysis system", PhD Thesis, December 2010, School of Marine Science and Technology, Newcastle University, UK.
6. Kongsberg, "Ship Performance System", Kongsberg Maritime AS publication, 2013, http://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/AB963D5AB36A752DC1257AF50041E9D4/$file/376812.pdf?OpenElement, cited September 2015.
7. Torben Munk (Propulsion Dynamics), "A CO2 Maintenance Index (Hull and Propeller Performance)", Ship Efficiency Conference, September 2009, Hamburg.
8. Bazari Z, 2012 "Ship Energy Efficiency – Developments and Lessons Learnt", Lloyd's Register, LRTA paper, September 2012.
9. Lloyd's Register 2015, "European Union Regulation on Monitoring, Reporting and Verification of Carbon Dioxide from Ships", Lloyd's Register Summary – EU MRV, Version 4.0 – May 2015.
10. Regulation (EU) 2015/757 on "the monitoring, reporting and verification of carbon dioxide emissions from maritime transport", and amending Directive 2009/16/EC, adopted by the European Parliament and the Council of 29 April 2015
11. "IMO train the trainer course material", developed by WMU, 2013.