INTERNATIONAL STANDARD

ISO 19030-3

First edition
2016-11-15

Ships and marine technology — Measurement of changes in hull and propeller performance —

Part 3: Alternative methods

Navires et technologie maritime — Mesurage de la variation de performance de la coque et de l'hélice —

Partie 3: Méthodes alternatives

Reference number
ISO 19030-3:2016(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 8, *Ships and marine technology*, Subcommittee SC 2, *Marine environment protection*.

A list of part of the ISO 19030 series can be found on the ISO website.

Introduction

Hull and propeller performance refers to the relationship between the condition of a ship's underwater hull and propeller and the power required to move the ship through water at a given speed. Measurements of changes in ship specific hull and propeller performance over time make it possible to indicate the impact of hull and propeller maintenance, repair and retrofit activities on the overall energy efficiency of the ship in question.

The aim of this document is to prescribe practical methods for measuring changes in ship specific hull and propeller performance and to define a set of relevant performance indicators for hull and propeller maintenance, repair, retrofit activities. The methods are not intended for comparing the performance of ships of different types and sizes (including sister ships) nor to be used in a regulatory framework.

This document consists of three parts.

— ISO 19030-1 outlines general principles for how to measure changes in hull and propeller performance and defines a set of performance indicators for hull and propeller maintenance, repair and retrofit activities.

— ISO 19030-2 defines the default method for measuring changes in hull and propeller performance and for calculating the performance indicators. It also provides guidance on the expected accuracy of each performance indicator.

— ISO 19030-3 outlines alternatives to the default method. Some will result in lower overall accuracy but increase applicability of the standard. Others may result in same or higher overall accuracy but includes elements which are not yet broadly used in commercial shipping.

The general principles outlined, and methods defined, in this document are based on measurement equipment, information, procedures and methodologies which are generally available and internationally recognized.

Ships and marine technology — Measurement of changes in hull and propeller performance —

Part 3: Alternative methods

1 Scope

This document outlines alternatives to the default method. Some will result in lower overall accuracy but increase applicability of the standard. Others can result in same or higher overall accuracy but includes elements which are not yet broadly used in commercial shipping.

The general principles outlined and performance indicators defined are applicable to all ship types driven by conventional fixed pitch propellers, where the objective is to compare the hull and propeller performance of the same ship to itself over time.

This document presents alternatives to measurement parameters (primary and then secondary) in Clause 4, then alternatives to measurement procedures (including alternative reference and evaluation periods) in Clause 5, describes the calculation of performance indicators in Clause 6, and finally the estimation of performance indicator accuracy in Clause 7. The structure used duplicates the structure of ISO 19030-2 to facilitate cross-reference between the two documents.

NOTE Support for additional configurations (e.g. variable pitch propellers) will, if justified, be included in later revisions of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3046-1, *Reciprocating internal combustion engines — Performance — Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods — Additional requirements for engines for general use*

ISO 19030-1:2016, *Ships and marine technology — Measurement of changes in hull and propeller performance — Part 1: General principles*

ISO 19030-2:2016, *Ships and marine technology — Measurement of changes in hull and propeller performance — Part 2: Default method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19030-1 and ISO 19030-2 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

4 Measurement parameters and alternatives

4.1 General

This clause explores alternatives to the primary and secondary measurement parameters defined for the default method in ISO 19030-2. Whether using ISO 19030-2 or ISO 19030-3 (method alternatives), in all instances, any instruments, automated equipment and sensors used shall be installed, maintained and calibrated in accordance with the specification in ISO 19030-2:2016, 4.3.

4.2 Proxy for the primary measurement parameters

4.2.1 General

Hull and propeller performance as defined in ISO 19030-1:2016, 4.1 gives measurements of ship speed through water and of power delivered to the propeller as the two primary measurement parameters. ISO 19030-2:2016, Clause 4, defines minimum sensor requirements for these two parameters.

If the primary measurement parameters cannot be measured or the minimum sensor requirements cannot be met, proxies can be used to approximate the parameters. As compared with the default method, this will generally result in reduced accuracy. Table 1 summarises relevant proxies. 4.2 and 4.3 describe the proxies and estimate impact on accuracy. Speed data should be measured in m/s or converted from knots to m/s using the conversion factor 1 knot = 0,514 4 m/s.

Table 1 — Sensor proxies for the primary measurement parameters

Parameter	Proxy	Measurement approach	Unit
Speed through water	Speed Over Ground (SOG)	Calculate SOG from GPS/navigation system	(m/s)
Delivered power	Alternative methods for estimating of delivered power (other than ISO 19030-2:2016, Annex B and Annex C)	Alternatives to ISO 19030-2:2016, Annex B and Annex C approach	(kW)

4.2.2 Proxy for speed through water measurement (speed over ground measurement)

4.2.2.1 General

It is possible to approximate a ship's speed through water using speed over ground measurements. Speed over ground measurements are typically directly available as, or can be calculated based on information from, the GPS or navigation system. Using speed over ground as a proxy introduces an uncertainty due to the influence of currents. This uncertainty will affect all ships, but to varying extents depending on the area of operation and the ship's frequency of encountering current speeds with a similar magnitude to the ship's speed through the water (e.g. current speed greater than 10 % of the ship's speed through the water). The impact of the uncertainty associated with the use of this proxy is estimated and discussed in ISO 19030-1:2016, Annex A.

$$V_d = 100 \cdot \frac{v_m - v_e}{v_e} \tag{1}$$

where

V_d is the percentage speed loss;

v_m is the measured speed through water;

v_e is the expected speed through water.

When used as a proxy, speed over ground is a direct substitution for the measured speed (V_m) through water (in m/s) as defined in ISO 19030-2:2016, 5.4.7.2 and Formula (3) and in Formula (1).

4.2.2.2 Procedure for calculating the average speed over ground

The vessel's speed over ground is a key quantity for measuring the changes in hull and propeller performance. This data should be as accurate and precise as is practical.

When automatic recording systems for the vessel's speed over ground are not available, alternative methods to measure, calculate, and record the speed over ground are required.

When manual readings are required, the interval between measurements should be maintained as much as is practical.

When a calculation of distance travelled per period of time is used, it is important to consider how the distance travelled is measured and the method used shall be clearly documented. To ensure minimum uncertainty of the performance value, speed and draught shall be kept approximately constant over the period of time used to determine speed.

A clear procedure shall be documented to ensure that measurements and calculations are consistently performed.

4.2.3 Proxy for delivered power (Alternative methods for estimating delivered power other than ISO 19030-2:2016, Annex B and Annex C)

4.2.3.1 General

As one of the default methods for estimating delivered power, ISO 19030-2:2016, Annex B describes an approach for estimating delivered power from fuel consumption data, using mass or volumetric flow meters. This alternative considers situations where mass or volumetric flow meter data is not available.

This alternative method assumes a conventional propulsion system of a two-stroke main engine directly coupled to a propeller (no gearbox), and without a shaft generator (power take-off). The fuel consumption shall be measured for the main engine alone and shall not include consumption by auxiliaries, boilers or returns.

The average delivered power over each sample's period is calculated using Formula (2), which is the same as ISO 19030-2:2016, Formula (C.1):

$$P_B = f\left(M_{FOC} \times \frac{LCV}{42{,}7}\right) \tag{2}$$

where

M_{FOC} is the mass of consumed fuel oil by main engine (kg/h);

LCV is the lower calorific value of fuel oil (MJ/kg);

f is the SFOC reference curve.

In addition to the uncertainty inherent in any sensors, use of this proxy can introduce considerable additional uncertainty. This is mainly due to the influence of changes in fuel quality, the accuracy of the fuel mass measurement (see the section below for greater detail), and the influence of changes in SFOC over time on account of engine degradation, all of which it is difficult to control for. The impact of the uncertainty associated with the use of this proxy is estimated and discussed in ISO 19030-1:2016, Annex A.

4.2.3.2 Obtaining the mass of fuel consumed (M_{FOC}) and estimating the uncertainty in the quantification of mass of fuel consumed

When automated systems are not available to automatically measure fuel consumed, alternative methods can be considered. The choice of method will depend on the available equipment installed on the vessel.

When manual readings are required, either by physical sounding of tanks or by taking manual meter readings, the interval between measurements shall be maintained as much as is practical, with a frequency no less than daily, and with the effect of any time zone changes accounted for when calculating average parameters.

Any meters used for taking measurements shall be properly maintained, and their accuracy ensured with periodic testing and calibration.

When manually sounding tanks, it is important to consider the trim and list of the vessel. A consistent, documented process for taking accurate physical soundings of the tanks shall be used.

For both volumetric flow meters and sounding measurements, corrections shall be applied for temperature and density. This shall follow the correction procedure specified in ISO 19030-2:2016, Annex C.

Sources of uncertainty associated with obtaining measurements of the mass of fuel consumed by tank soundings and flow meters, respectively, include the following:

— measurement errors due to ship motions, trim and/or list, errors due to manual recording or calculation of total fuel consumed, errors due to the timings at which different tanks are sounded, errors due to the inclusion of waste (sludge) in measured fuel consumption, uncertainty in the dimensions of the tank and errors in the temperature and density measurement and correction calculation;

— measurement uncertainty of the flow meter and errors in the temperature and density measurement and correction calculation;

— error propagation due to calculating fuel consumption from differences of inflow and outflow of fuel.

4.2.3.3 Estimating the SFOC

If available, the SFOC curve used shall be based on actual shop tests of the specific engine in question covering all relevant engine output ranges and shall be corrected for environmental factors as per ISO 3046-1, and for a normal fuel of 42 700 kJ/kg.

If actual shop tests of the specific engine in question covering all relevant engine output ranges are not available, then the SFOC characteristic for a given engine type shall be obtained from the engine manufacturer.

4.3 Secondary measurement parameters and alternatives

4.3.1 General

For the isolation of comparable reference conditions and for the filtering and normalization procedures, both environmental factors and the ship's operational profile shall be measured. To this effect, ISO 19030-2:2016, 4.3 defines a number of secondary measurement parameters and minimum sensor requirements for each of these parameters.

If these parameters cannot be measured or the minimum sensor requirements cannot be met, proxies can be used to isolate comparable reference conditions and to enable filtering and normalization procedures.

In some cases, instead of adopting a proxy, one may have to modify the reference condition criterion (defined in ISO 19030-2:2016, 6.3.2) or modify the analysis procedure; any such modification shall be fully and transparently documented and justified.

Table 2 — Sensor proxies for normalization procedures and reference condition criterion

	Alternative measurement
Wind speed	Anemometer with lower accuracy than as specified in ISO 19030-2
Draught (fore and aft)	Observed directly or derived from observed draught (fore and aft) in port
Water depth	Calculated from electronic nautical charts and the ship track from (D)GPS
Rudder angle	None

4.3.2 Alternative measurement of wind speed

If measurements of the relative wind speed according to the sensor accuracy requirement specified in ISO 19030-2 are not available, lower accuracy sensors may be used instead. In all other respects, the procedure specified in ISO 19030-2 shall be followed.

When manual readings are required, the interval between measurements shall be maintained as much as is practical, with a frequency no less than daily and with the effect of any time zone changes accounted for. These recordings shall reflect representative wind conditions for the period in question.

4.3.3 Alternative measurement of static draught (fore and aft)

The vessel's draught at sea can be recorded from the loading computer. Input shall reflect the vessel's condition at the beginning of sea passage, or may be derived from observed draught and trim in port. When manual recording methods are used, the interval between measurements shall be maintained as much as is practical. If there is a significant change in displacement, then draught values shall be updated to reflect actual loading conditions.

Draught marks, when used, can be hard to read due to poor lighting, fading coatings, hull fouling, and conditions other than calm. A clear procedure shall be documented to ensure that personnel take accurate readings.

The impact of the uncertainty associated with the use of this proxy is estimated and discussed in ISO 19030-1:2016, Annex A.

4.3.4 Alternative measurement of water depth

In the event that automated logging of the water depth is not available, whenever the ship is operating in water depths less than 100 m, this data shall be obtained from electronic nautical charts and recorded alongside other secondary data.

5 Measurement procedures and alternatives

5.1 General

This clause discusses how measurement data is to be acquired, stored and prepared.

5.2 Data acquisition

ISO 19030-2:2016, 5.2, specifies that the following data shall be recorded simultaneously at a frequency of 1 signal every 15 s (0,07 Hz) or above and collected by a data acquisition system (e.g. a data logger). If a system for data collection at this frequency is not available, this document permits the measurements described in Clause 4 to be recorded less frequently (e.g. as noon data) with the following specifications:

— the data sampling rate shall remain unchanged over the full measurement period (reference period and evaluation period), except for changes created by time zone change (see below);

— primary measurement parameters (speed, power from either shaft torque and rpm or fuel consumption) shall be averaged over the period;

— secondary measurement parameters shall, as much as possible, be collected at the same sampling rate as the primary measurement parameters, or no less frequently than 1 signal per day. With the exception of wind and draught, these values shall be short-term average values (e.g. averages over 1 min) taken at the point in time the observation is obtained.

NOTE 1 It is often the case that the daily report is filed at noon local time. If a ship is changing time zone during the voyage, this will mean that occasionally, the time period between a daily noon report is slightly more or less than 24 h (e.g. typically 1 h). This variation will have a negligible impact on the accuracy of the estimation and can be tolerated.

To guide the interpretation of performance measurements, the influence of two different sampling and averaging periods (frequency according to specification in ISO 19030-2:2016, Table 2, and daily frequency) on performance value uncertainty is addressed in Clause 7.

If data cannot be automatically collected, data shall be collected manually. This introduces an uncertainty partially due to the increased probability of human error over error probability in automated data collection systems, but also due to the necessity of reducing the sampling frequency.

NOTE 2 Lower frequency of data collection increases uncertainty in many ways. It reduces the number of data points available from which the average performance values are calculated, and it increases the uncertainty effects related to the use of primary parameter average values (e.g. the use of an average speed and power if both experience a significant variation due to changes in operation over the time period of the sample). Both of these effects on performance indicator uncertainty are incorporated in the treatment of uncertainty in ISO 19030-1:2016, Annex A.

5.3 Data storage

Data should be stored according to the procedure in ISO 19030-2:2016, 5.3.

5.4 Data preparation

5.4.1 General

Data shall generally be prepared according to ISO 19030-2:2016, 5.4.

Where the frequency of acquisition is one measurement per ten minute period or higher, data shall be filtered and validated according to the procedure in ISO 19030-2:2016, 5.4.5. Where the intervals between data acquisition are longer than a period over which the data can be expected to be approximately stationary (e.g. for noon data), the low frequency of data also precludes the preparation of the blocked dataset for validation procedures, ISO 19030-2:2016, Annex J.

Where reliable measurements of relative wind speed and direction have been acquired, correction for wind resistance according to the procedure in ISO 19030-2:2016, 5.4.6 and Annex G shall be applied. If the required data is unavailable, this step has to be omitted.

5.4.2 Alternative procedure for expected speed calculation

5.4.2.1 General

For calculation of performance values (PVs), the procedure defined in ISO 19030-2:2016, 5.4.7 shall be followed.

5.4.2.2 Alternative procedure for expected speed calculation

In the case that speed-power reference curves are available from external sources for different loading conditions, but do not cover a relevant intermediate draught range, additional speed-power curves shall be estimated by interpolation between available curves or by applying generally accepted power estimation approaches. It has to be documented how the curves have been built.

5.4.2.3 Alternative procedure for generating reference curves without external sources

5.4.2.3.1 General

In the case that no speed-power reference curves are available from external sources, speed-power reference curves shall be extracted from in-service data following one (or a combination) of the following methods:

— conducting "permanent trial trips", as detailed in 5.4.2.3.2;

— collecting data by "passively monitoring" the vessel as it operates, as detailed in 5.4.2.3.3.

Both methods can only be used if the measurement parameters and measurement procedures as defined in ISO 19030-2:2016, Clause 4 and Clause 5 are followed.

NOTE It is not yet known which of these approaches give the same, lower, or a higher accuracy as compared to the default method.

5.4.2.3.2 Acquiring data for the permanent trial trip approach

The following steps shall be applied.

a) Switch on autopilot and set on mode with lowest rudder activity (to be maintained during the entire sets of runs).

b) Adjust main engine rpm approximately according to intended speed level (start with lowest).

c) Wait approximately 30 min until speed/rpm level is stable.

d) Start recording period (marker on permanent recording) and record for at least 1 h without changing anything.

e) End recording period (marker on permanent recording).

f) Adjust main engine rpm according to intended speed level (next higher speed level).

g) Repeat c) to f) until set of recording runs at given loading condition is finished.

The minimum time of steady/calm condition needed for one complete set of recording runs at one loading condition at three speed levels is approximately 6 h.

5.4.2.3.3 Acquiring data for the passive monitoring approach

Acquiring data for the passive monitoring approach uses data gathered during in-service operation. It requires no additional steps that would not already be undertaken.

5.4.2.3.4 Conditions

For both approaches, the data collection shall satisfy the following conditions.

a) Data shall be collected within the shortest possible time interval and no longer than six months.

b) Representative speed levels and loading conditions (both draught and trim), for the considered Reference and Evaluation periods, shall be covered in the data.

c) The underwater hull and propeller shall experience no significant changes to their condition.

When applying permanent sea trials, the data collection shall be performed at recorded draught and trim during voyage periods specified by the following criteria.

a) Deep water: shallow water effect excluded according to Formula (6) and Formula (7).

b) Calm sea: Trials should be conducted in calm seas to minimize ship motions. The “calm-sea” filter criterion used shall be defined and documented. In addition, either pitch and roll motions or sea state shall be documented.

c) “Steady”: no change of course, acceleration or deceleration for the duration of the trial period, low rudder activity autopilot setting.

d) Head wind: absolute value of the relative wind angle below 40°.

For the passive monitoring approach, conditions are controlled for by the application of reference conditions to filter the measured data.

NOTE For the passive monitoring approach, filtering out rough seas using measurements of ship motions improves the precision of the acquired speed-power reference curves. Therefore, sensors for measurement of ship motions should be used if at all possible. The sensor type and accuracy, as well as the “calm-sea” filter criteria used, should then be documented.

The approaches to obtaining delivered power, as well as minimum required sensors and sensor accuracies for each, are specified in ISO 19030-2:2016, Annex B and Annex C, respectively.

The obtained datasets at every speed level for a given loading condition shall be filtered for outliers according to Annex I and validated according to ISO 19030-2:2016, Annex J. It shall furthermore be filtered according to the reference conditions defined ISO 19030-2:2016, 6.3.2.

After filtering the delivered power, values shall be corrected for wind following the method outlined in ISO 19030-2:2016, Annex G.

5.4.2.3.5 Fitting speed-power curve to obtained data

For data obtained in each loading condition, a speed-power curve shall be fitted to the obtained data, and this curve shall be used as a speed-power reference curve for the loading condition in question. The mathematical form of this curve and details about the curve fitting shall be documented.

As an example, the following curve fitting approach may be used. The method uses a simple form for the speed-power relationship, as given in Formula (3):

$$P = aV^b \tag{3}$$

where

P is the delivered power (corrected for wind);

a and b are unknown constants to be calibrated from the data.

For the curve fitting, the model is linearized by taking logarithms of both sides, and the model for the curve fitting is thus as given in Formula (4):

$$\log\left(P\right) = \log\left(a\right) + b\log\left(V\right) + \varepsilon \tag{4}$$

Now, the parameters **log(*a*)** and **log(*b*)** can be obtained by fitting a line in the **[log(*V*), log(*P*)]** space using the linear least squares method.

NOTE Epsilon corresponds to the measurement error.

If a power model of another form or another fitting procedure is used, the power model and the fitting procedure shall be documented and a visualization of the measured data versus the fitted curve shall be made available.

The coefficient of determination (R^2-value) for the generated speed-power curves shall be above 0,8. The coefficient of determination shall be calculated based Formula (5):

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(P_{\mathrm{m}}^{i} - P_{\mathrm{e}}^{i}\right)^2}{\sum_{i=1}^{N}\left(P_{\mathrm{m}}^{i} - P_{\mu}^{i}\right)^2} \tag{5}$$

where

P_{m} are the measured (wind corrected) delivered power readings;

P_{e} are the expected power readings from the created curve;

P_{μ} is the mean observed delivered.

6 Calculation of performance indicators (PIs)

6.1 General

This clause discusses how different performance indicators (PIs), defined in ISO 19030-1 shall be calculated based on performance values (PVs) extracted from a prepared data set.

NOTE Performance indicators are dimensioned in terms of speed. A method for calculating performance indicators in terms of power is provided in ISO 19030-2:2016, Annex K.

6.2 Definition of performance indicators

This document uses the same definitions of the four performance indicators as given in ISO 19030-2:2016, Table 3.

6.3 Calculation of performance indicators

6.3.1 General

The same steps apply for the calculation of each performance indicator, PI, as stipulated in ISO 19030-2:2016, 6.3. That is, as follows:

— determination of reference conditions;

— establishment of reference period and evaluation period;

— extraction of subsets of PVs from the complete set with PVs that fulfil reference conditions for reference period and evaluation period;

— calculation of the PI;

— assessing the accuracy of the PI.

6.3.2 Determination of reference conditions

The reference conditions applied to filter the data are a function of both the available data (i.e. a function of which sensors are fitted) and the frequency with which the measurements are taken. If possible, the reference conditions specified in ISO 19030-2 should be applied. If not possible, variations can be considered. Irrespective of how frequently the data is obtained, the following conditions should be met:

— water temperature is above +2 °C and there is no other indication that the vessel is trading on ice;

— the wind speed is between 0 m/s to 7,9 m/s (BF 0 and BF 4); ≤BF 4 (0 knots to 16 knots; 0 m/s to 7,9 m/s);

— water depth is greater than the larger of the values obtained from Formula (6) and Formula (7):

$$h = 3\sqrt{B \cdot T_{\mathrm{M}}} \tag{6}$$

$$h = 2{,}75\frac{v_{\mathrm{s}}^{2}}{g} \tag{7}$$

— delivered power is within the range of the power values covered by the available speed-power reference curves;

— displacement has to be within ±5 % of the displacement values for the available speed-power reference curves;

— if delivered power is estimated by the method outlined in ISO 19030-2:2016, Annex C or any alternative method using measurement of mass of fuel consumed described in this document, the estimated delivered power has to be within the range of power values covered by the available SFOC curve.

Furthermore, if high frequency (e.g. every 5 min) measurements of the requisite primary and secondary parameters are available, then the reference condition shall be absolute rudder angle value is <5°.

6.3.3 Establishment of reference period and evaluation, and alternative durations of reference and evaluation periods

ISO 19030-2:2016, 6.3.3 specifies the period over which the calculations of $V_{\mathrm{d,ref}}$ and $V_{\mathrm{d,eval}}$ are made for each of the definitions of performance indicator. However, there may be situations where it is necessary or desirable to measure hull and propeller performance over shorter or longer periods of time than those stipulated, for example during the period of a time charter.

If $V_{\mathrm{d,ref}}$ and $V_{\mathrm{d,eval}}$ are calculated based on a period less than one year, the reference and evaluation period should be chosen so that they are representative of a full range of operational and environmental conditions that the ship is likely to encounter. This length of time will depend on the ship, the area of operation and the operators.

NOTE The influence of three different reference and evaluation period durations (3, 6 and 12 months) on performance value uncertainty is discussed in ISO 19030-1:2016, Annex A and quantified in Table 5.

6.3.4 Extraction of subsets of performance values from the complete set with performance indicators that fulfil reference conditions for reference periode(s) and evaluation period

For any variation in this document, the procedure used mirrors the procedure in ISO 19030-2:2016, 6.3.4.

6.3.5 Calculation of the PI

For any variation in this document, the procedure used mirrors the procedure of ISO 19030-2:2016, 6.3.5.

7 Accuracy of the performance indicators (PIs)

7.1 General

Appropriate use of the performance indicators (PIs) for decision-making purposes is dependent on understanding to what extent uncertainty influences the accuracy of each performance indicator.

7.2 Standard combinations or primary parameters, secondary parameters and measurement procedure details

In the preceding clauses, the additional uncertainty associated with individual alternatives to the default method has been indicated. In this clause, the procedure for calculating the combined effects of multiple alternatives on the accuracy of the performance values is described. For these purposes, four scenarios with different combinations of alternatives have been defined.

Table 3 — Summary of primary and secondary measurement parameters and measurement procedures for the three standard variations to this procedure

Method	Speed	Delivered power	Frequency of measurement	Trim/draught	Water depth	Rudder angle	Wind speed and direction
3-1	Speed log (as per ISO 19030-2)	Part 3 fuel consumption proxy (as per ISO 19030-3:2016, 4.1.2)	Every 15 s (as per ISO 19030-2)	From loading computer or calculated from draught mark readings (as per ISO 19030-2)	Echo sounder (as per ISO 19030-2)	Rudder angle indicator (as per ISO 19030-2)	Anemometer (as per ISO 19030-2)
3-2	Speed over ground (as per ISO 19030-3:2016, 4.1.1)	Torque meter and rpm meter (as per ISO 19030-2)	Every 15 s (as per ISO 19030-2)	From loading computer or calculated from draught mark readings (as per ISO 19030-2)	Echo sounder (as per ISO 19030-2)	Rudder angle indicator (as per ISO 19030-2)	Anemometer (as per ISO 19030-2)
3-3	Speed log (as per ISO 19030-2)	Torque meter and rpm meter (as per ISO 19030-2)	Daily (as per ISO 19030-3:2016, 5.1)	From loading computer or calculated from draught mark readings (as per ISO 19030-2)	Echo sounder (as per ISO 19030-2)	None (as per ISO 19030-3: 2016, 4.2)	Anemometer (as per ISO 19030-2)
3-4	Speed over ground (as per ISO 19030-3:2016, 4.1.1)	Part 3 fuel consumption proxy (as per ISO 19030-3:2016, 4.1.2)	Daily (as per ISO 19030-3:2016, 5.1)	From loading computer or calculated from draught mark readings (as per ISO 19030-2)	Echo sounder (as per ISO 19030-2)	None (as per ISO 19030-3: 2016, 4.2)	Anemometer (as per ISO 19030-2)

7.3 Estimations of the uncertainty in the period average performance value

The uncertainty of the performance value is both a function of the measurement sensor uncertainties and the measurement procedures. ISO 19030-1:2016, Annex A describes a method for estimating the influence of changes to the primary and secondary sensor measurement accuracies, and the specifications to the measurement procedure. This method deploys a simulation of a reference ship's operation in combination with a simulation of the data measurement, sampling and analysis processes.

In order to simplify the range of technical and operational parameters to an extent that makes the modelling simple enough to be computationally tractable, a number of assumptions are made. These assumptions are listed, along with justifications, in Table 4, and discussed in greater detail in ISO 19030-1:2016, Annex A.

Table 4 — Summary of assumptions

Assumption	Effect on PI (bias/precision/both?)	Included?	Justification
Sample size	Precision	Yes	
Sensor precisions	Precision	Yes	
Sensor bias	Bias and precision	No	Bias assumed to be constant between time periods and therefore cancels The effect on precision is small and assumed to be negligible
Sensor drift	Both	No	Sensors assumed to be calibrated/ maintained
Speed variability/day	Bias	No	Assumed that over three-month periods the daily speed variability cancels
Operational profile	Bias	No	Assumed to be similar over three month periods
Time-dependent effect — P increase	Bias	No	Assumed to be linear with time
Time-dependent effect — V loss	Precision	No	Insignificant (eg.: V loss changed from ~40 % to 5 % over 90 days -> uncertainty is reduced by 0,29 %)
Model error	Bias: if the operating conditions are the same in the reference and evaluation period, model error induces negligible bias. If they are not the same, significant bias can be induced. Precision: model error can also have a moderate impact on the precision	No	While these can be significant, the assumption made is that the sourcing of the speed, draft, trim and power relationship is done rigorously such that the data used is a good likeness to the ship's actual performance.
Human error	Both	No	Cannot be quantified

Overall, there are two main justifications for the acceptability of these assumptions.

a) The evidence supplied by the comparison between the performance uncertainty estimate calculated using a Monte Carlo simulation and the performance uncertainty estimate obtained by inspecting measured data, as presented in Reference [1].

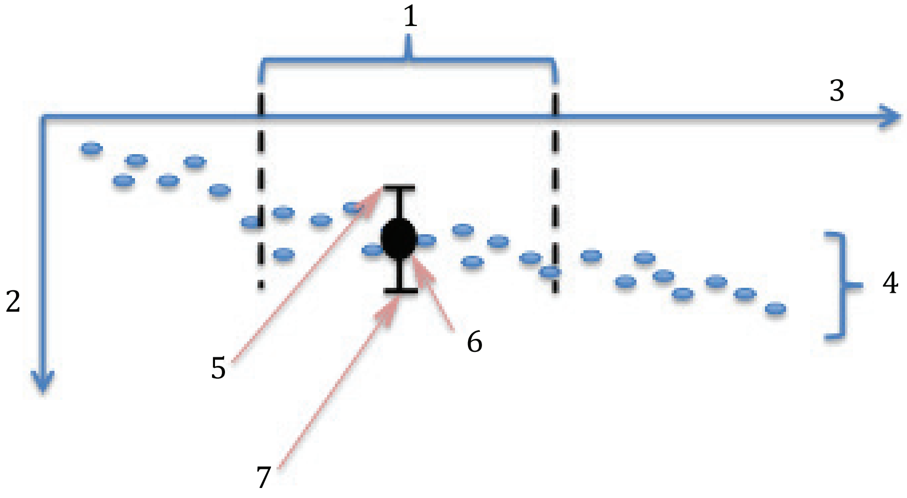
b) The fact that these assumptions are predominantly common to both the reference and evaluation periods and therefore should be removed by the use of the Performance Indicators, which look at relative rather than absolute performance.

Under the assumptions of measurement accuracy listed in ISO 19030-1:2016, Annex A, Table 2, the uncertainty analysis method is applied to each of the four standard variations listed in Table 3 with the results, expressed as the uncertainty to a 95 % confidence interval provided in Table 5 (i.e. under this standard variation, the 'true' value is expected to lie between the values listed in Table 5 with a probability of 95 %). Figure 1 shows the values of Table 5 interpreted as the bounding limits of an error bar on the Performance Value.

The simulation parameters and assumptions are considered to be representative for the ship types and sizes for which this document is intended. However, the technical and operational specifics of an individual ship could create significant differences in the uncertainties of the different part's measurement methods. Consequently, it is advised that when using these quantifications of uncertainty, attention is paid to ensure the applicability of the key assumptions and that these results are treated as indicative values only.

Table 5 — Estimates of the uncertainty, u_{v_d}, to a 2 sigma 95 % confidence interval, for specific combinations of measurement parameters and reference and evaluation period

	3 month period	6 month period	12 month period
ISO 19030-2 methods	0,38 %	0,27 %	0,19 %
ISO 19030-3–1	0,50 %	0,36 %	0,25 %
ISO 19030-3–2	0,57 %	0,40 %	0,29 %
ISO 19030-3–3	3,40 %	2,46 %	1,76 %
ISO 19030-3–4	6,30 %	4,57 %	3,25 %



Key

1 reference or evaluation period

2 hull and propeller performance

3 time

4 95% confidence range

5 performance value + u_{v_d}

6 performance value

7 performance value − u_{v_d}

Figure 1 — Uncertainty as the upper and lower bound values of an error bar on the performance value

7.4 Calculating the performance indicator and estimating the accuracy of the performance indicator

The uncertainty of the PI quantification shall be calculated from the estimates of the uncertainty in the period average performance values from which the PI is calculated. The procedure for calculation of PI uncertainty is given in Formula (8), with the inputs to the equation provided by the performance value uncertainties given in Table 5. This quantification of uncertainty shall be included in any documentation containing values of Performance Indicators. If the reference and evaluation periods have the same duration, then the average performance value uncertainties, which form the input to the calculation, will be the same. In such cases, the performance indicator uncertainty is the product of √2 and the performance value uncertainty, as listed in Table 6.

$$u_{k_{\mathrm{HP}}} = \sqrt{u_{\hat{v}_{\mathrm{d,eval}}}{}^{2} + u_{\hat{v}_{\mathrm{d,ref}}}{}^{2}} \tag{8}$$

where

$u_{k_{\mathrm{HP}}}$ is the uncertainty (to 95 % confidence interval) of the estimated PI value;

$u_{\hat{v}_{\mathrm{d,eval}}}$ is the uncertainty (to 95 % confidence interval) of the calculated percentage speed loss during the evaluation period;

$u_{\hat{v}_{\mathrm{d,ref}}}$ is the uncertainty (to 95 % confidence interval) of the calculated percentage speed loss during the reference.

Table 6 — Estimates of the performance indicator uncertainty, to a 2 sigma, 95 % confidence interval for the specific combinations of measurement parameters and reference and evaluation period

	3 months (90 days)	6 months (180 days)	12 months (360 days)
ISO 19030-2 methods	0,53 %	0,38 %	0,27 %
ISO 19030-3-1	0,71 %	0,50 %	0,35 %
ISO 19030-3-2	0,80 %	0,57 %	0,40 %
ISO 19030-3-3	4,80 %	3,47 %	2,49 %
ISO 19030-3-4	8,89 %	6,44 %	4,58 %

In general terms, the absolute uncertainty is reduced through any of the following:

— increasing the accuracy of sensors and measurements of the PI calculation’s inputs;

— increasing the frequency of measurements;

— increasing the time period of the reference and evaluation period.

The results in Table 5 and Table 6 give an indication of the sensitivity of the uncertainty to variations in these specifications. If using a non-standard combination of sensors and measurements, this can guide the user towards an expected uncertainty. However, the interaction of the different sources of uncertainty is not straightforward and so for anything other than small variations to the four standard procedures defined in Table 5, it would be necessary to reapply the method described in ISO 19030-1:2016, Annex A, or similar, in order to estimate the impact on performance value uncertainty.

The uncertainty of the PI is influenced by the specifications of the measurement parameters and measurement procedure. When this document is applied to measure small changes in performance, a lower (better) uncertainty is likely to be required than when measuring large changes in performance.

This document does not dictate a minimum level of uncertainty in the PI. Different levels of uncertainty may be appropriate to different applications, depending on the criticality or risk associated with the decision.

Bibliography

[1] Aldous L., Smith T., Bucknall R., Thompson P. *Uncertainty Analysis in Ship Performance Modelling Ocean Engineering*. 2015

ICS 47.020.99

Price based on 15 pages