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Original Paper

A new method to analyse the speed power performance of operating ships and its implementation

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Abstract: Ship operators need means to analyse their fleet's performance in order to maintain their competitiveness. Important decisions such as voyage planning and scheduled maintenance, are all made based on a ship's performance. However, there is no reliable method to estimate a ship's performance. ISO19030 provides a means to measure the changes in performance but is only applicable to data collected over a relatively long period of time and is unsuitable for comparing the performance of sister ships. In this study, we implemented a software to analyse a ship's performance. To meet the ship operator's requirements, a new speed power performance analysis method based on ISO15016:2015 is proposed. The proposed method first evaluates the added or decreased resistance due to the environmental changes including wind, waves and water density first. Then, the measured shaft power is corrected by direct power method and finally corrected to reference displacement for comparison. The results of its implementation, a software called SPA, and its application to two ships, a 176K bulk carrier and an 8600TEU container carrier, are described herein.

Keywords: Ship performance analysis (SPA), ISO15016:2015, ISO19030, Speed power performance

1. Introduction

Ship operators need a means to analyse their fleet's performance in order to maintain their competitiveness. Important decisions such as voyage planning and scheduled maintenance are all based on the ship's performance. However, there seems to be no reliable means to estimate a ship's performance. The most widely used measurements to estimate a ship's performance are fuel consumptions, but even with weather filtering, it is difficult to identify how much fuel consumption is due to environmental forces such as wind and waves, and how much is due to the ship's performance itself.

In 2016, ISO19030 was developed in order to prescribe practical methods for measuring changes in ship specific hull and propeller performance **[1]**. The emphasis was laid on practical methods, and many analysis techniques, such as calculating added resistance due to waves, were not included in the standard, as there was no practical means of collecting the data necessary to apply such techniques at the time. Instead, filtering and averaging were introduced instead to deal with environmental effects that were not accounted for in the standard. The result was a practical method that measures a ship's performance with the limitations that it can only be used to compare ship specific changes relatively and unsuitable for comparing different ships, with rather coarse time resolution (the averaging period should be at least 3 month or more and typically a year). However, ship operators need a means by which they can analyse their fleet's performance for each leg of the journey and often day by day. Decisions to increase a ship's efficiency are made day to day and three months averaged value of a ship's performance is far too late and coarse to be useful in a decision-making process.

There have been some previous research on applying ISO19030 methods for the analysis of a ship's performance. Researches outlined in **[2]-[5]** are notable examples. All authors

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commonly express concerns regarding filtering performance, and regret that the ISO19030 cannot provide means of comparing performance between ships or within shorter periods.

There has been other research that has tried to analyse a ship's performance using different approaches. Notably, J. Park *et al.* **[6]** used machine learning to predict a decrease in performance due to fouling. D. Gundermann *et al.* **[7]** used a simple regression model to obtain speed and power relationship for cases where no reference data are available. M. Jeon *et al.* **[8]** used a meta-regression model to predict fuel consumption. However, all these attempts did not consider a physical model of the wind and waves, and were only based on previous data; therefore, they cannot reflect changes in the operational profile or environment well.

This paper implements a software to analyse a ship's performance. To meet a ship operator's requirements, a new analysis method based on ISO15016:2015 is proposed **[9]**. ISO15016:2015 is the amended standard of the ship speed trial analysis method. Its accuracy objective of 2% in shaft power and 0.1knots in speed was verified from many sources during its development process as it is being used in contracts and mandatory regulations such as the reference speed in EEDI calculations **[10]**. ISO15016:2015 was also considered during ISO19030 development and many parts of ISO19030, such as wind correction, were directly referenced. The results of its implementation and application to two ships, a 176K bulk carrier and 8600TEU container, are described herein.

2. Analysis method

2.1 Overall process

The overall process of the new proposed method is basically the same as ISO19030 and ISO15016:2015. First, un-processable data, such as when the ship changes direction or moving in shallow water, are removed by filtering. Then increases in resistance due to environmental forces are estimated by the same method used in ISO15016:2015. Then, these resistance increases are used to correct power using the direct power method used in ISO15016:2015. For the purpose of comparison, the analysis results are further corrected to standard displacement. The overall analysis procedure is summarised in **Figure 1**, and **Table 1** summarizes the difference between the proposed method and ISO9030.

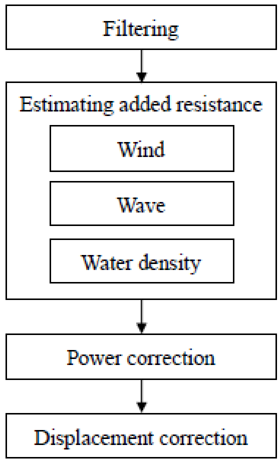

Figure 1: The overall analysis procedure

2.2 Filtering

In ISO19030, filtering is used to remove outliers and only leave the part of the data when the ship is steadily cruising. However, as noted in B. J. Park *et al.* **[11]**, the filtering in ISO19030 may have unwanted effects. In ISO15016:2015, unfiltered data is applied as the speed trial is only conducted in a very calm environment and few measurements are taken. The analysis method used in this paper employs very simple filters to avoid any unwanted effects:

① Remove when speeds are too low or high. Usually the speed range in the model test is used as a reference and any data with the speed outside the range is discarded.

② Remove data when rudder angle is larger than 5° to remove when changing direction.

③ Remove data when the ship is operating in shallow water.

Table 1: Comparison of the proposed method and ISO19030

	Proposed method	ISO19030
Filtering	Simple filtering criteria	Statistical filtering scheme
Wind correction	Same as ISO15016:2015	Same as ISO15016:2015
Wave correction	Same as ISO15016:2015	None
Water density correction	Same as ISO15016:2015	Same as ISO15016:2015
Added resistance correction	Power correction	Either power or speed correction
Displacement correction	Same as ISO15016:2015	Same as ISO15016:2015
End results	Corrected Speed-Power values	Performance Indicator (single value)

2.3 Estimating added resistance

Resistance increase due to wind, waves and differences in water density are estimated with the same method as used in ISO15016:2015. For wind resistance, ISO19030 and ISO15016:2015 use the same method. A detailed method for calculating the resistance increase due to wind is presented in Annex C of ISO15016:2015.

Wave resistance, it was not included in ISO19030 as no practical means of measuring wave parameters were available. However, as noted in B. J. Park *et al.* **[12]** there exist publicly available wave data from sources such as the National Oceanic and Atmospheric Administration (NOAA). ISO15016:2015 in Annex D includes STAWAVE II and a theoretical method for wave resistance calculation, but because the theoretical method requires more detailed ship geometry data and requires more time for calculation, STAWAVE II, even with its limitation of only being able to calculate waves within ±45° of the ship's heading, is a more practical method to use.

An increase in resistance due to differences in water density can be calculated as detailed in Annex E of ISO15016:2015 from the water temperature, which is also available from weather services even if the ship is not equipped to record such data.

2.4 Power correction

Once all resistance increases are estimated, they are used to correct the measured power value. The required correction for power is calculated using **Equation (1)**.

$$\Delta P = \frac{\Delta R \cdot V_s}{\eta_{D\,id}} + P_{D\,m\,s}\left(1 - \frac{\eta_{D\,m\,s}}{\eta_{D\,id}}\right) \qquad (1)$$

where:

- ΔP is the required correction for power in watts;
- ΔR is the total resistance increase in newtons;
- V_s is the ship's speed through the water in metres per seconds;
- $P_{Dm\,s}$ is the measured delivered power in the operating condition in watts;
- $\eta_{Dm\,s}$ is the propulsive efficiency coefficient in the operating condition;
- $\eta_{D\,id}$ is the propulsive efficiency coefficient in the ideal condition.

ISO15016:2015 uses a load variation test to identify the ratio between the propulsive efficiency coefficient in the operating condition and in the ideal condition as shown in **Equation (2)**.

$$\frac{\eta_{D\,m\,s}}{\eta_{D\,id}} = \xi_P \frac{\Delta R}{R_{id}} + 1 \qquad (2)$$

where:

- ξ_P is derived considering the load variation effects as described in Annex J of ISO15016:2015;
- R_{id} is the resistance in the ideal condition in newtons.

However, as most ships does not perform a load variation test during a model test, if the results of the load variation test are non-existent, then ratio can be set to 1.

The corrected power is calculated by **Equation (3)**.

$$P_{D\,id} = P_{D\,m\,s} - \Delta P \qquad (3)$$

where:

- $P_{D\,id}$ is the corrected delivered power in the ideal condition.

Current correction is not included in the new method. The current correction method in ISO15016:2015 assumes that the measurements are taken in the same geographical location and therefore current can be expressed as a periodic function dependent on time. However, for operating ships, geographical location and the current affecting the ship's performance are always changing. Also, by using speed through water instead of speed over the ground, current effects are already partially considered in the speed measurements themselves.

2.5 Displacement correction

Each leg of the journey of an operating ship has different displacements, and to compare the analysis results, the differences in displacements has to be taken into account. This is achieved by first defining standard displacements for typical loading conditions such as laden and ballast for bulk carriers and 80% or 90% displacements for container carriers, and then using the displacement correction method in ISO15016:2015 to correct power for standard displacements. After displacement correction, analysis results can be compared with each other and even with the model test or sea trial results, if such data is available for the same loading conditions.

3. Implementation

A software implementing the analysis method described in section 2 called SPA (Ship Performance Analysis Software) was developed. SPA implements all functions necessary to handle a large amount of data, which is collected during the operation of the ship. Particular care is given to its practical application and the key functions are listed as below:

① Fast processing of a large amount of data using an internal database.

② Define custom filters to be applied as per the user's requirements.

③ Use of templates for ship definition, data column definition and filter definition, which will enable a user to reuse well-defined templates for subsequent analysis.

④ Custom select which measurements to use for speed, power, heading and environmental correction.

⑤ Review the results of applying filters, and the analysis results, in a table format inside the software.

⑥ Show the speed power graph inside the software for a quick review of the analysis results.

⑦ Output detailed analysis results in csv format for further analysis when necessary.

The main window of SPA is shown in **Figure 2**. The imported data, the results of applying filters, and the final analysis results can all be reviewed within the software as shown in **Figure 3**. It is also possible to quickly review the analysis results with a speed power graph as shown in **Figure 4**.

The data used in the SPA software have already been collected by the ship operators. **Table 2** summarises the input data for the SPA software. The output from the SPA software after analysis includes full calculation results in .csv format, which can be used later by the user. **Table 3** is a list of the output data.

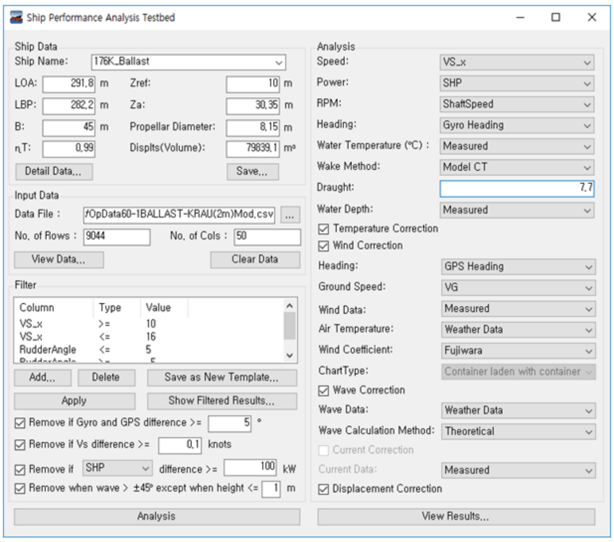

Figure 2: Main window of SPA

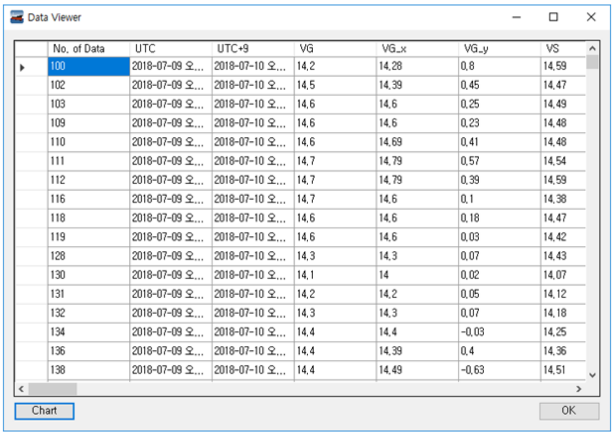

Figure 3: Results view window of SPA

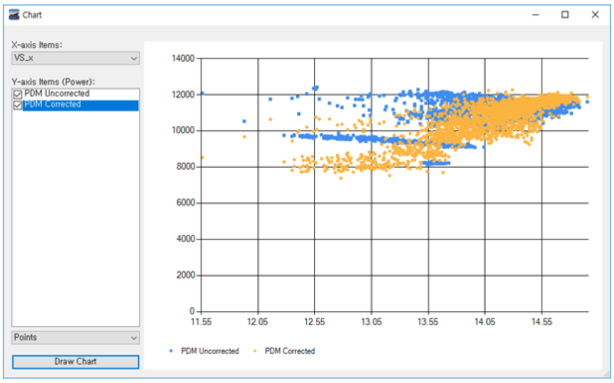

Figure 4: Results chart view window of SPA

Table 2: Input data for SPA software

Data category	Data items	Source
Speed	Speed through water Speed over ground Speed of shaft revolution	Speed log GPS Shaft power meter
Heading	Gyro heading GPS heading	Gyro GPS
Power	Shaft power Brake power Delivered power	Shaft power meter Calculated from fuel flow meter
Wind	Wind speed Wind direction	Anemometer
Wave	Wind wave height Wind wave period Wind wave direction Swell height Swell period Swell direction	Wave radar Weather service provider
Temperature	Air temperature Water temperature	Thermometer
Depth	Water depth	Echo sounder

Table 3: List of SPA software output data

Column Name	Description
UTC	Date and time
VG	Speed over ground
VS	Speed through water
Heading_GPS	GPS heading

Heading_Gyro	Gyro heading
Rudder_Angle	Rudder angle
h_M (Depth)	Water depth (measured)
h_W (Depth)	Water depth (weather data)
RPM	Speed of shaft revolution
Qs	Shaft torque
Psm	Shaft power
Pdm	Delivered power
BHP	Brake power
Vwr_Rel_M	Relative wind speed (measured)
psiwr_Rel_M	Relative wind direction (measured)
Air_Temp.	Air temperature
Rho_A	Air density
Vwt_Truei	True wind speed
psiwt_Truei	Ture wind direction
Vwtref_Truei	True wind speed at reference height
psiwtref_Truei	True wind direction at reference height
Vwrref_Reli	Relative wind speed at reference height
psiwrref_Reli	Relative wind direction at reference height
Caa(0)	Wind resistance coefficient at ship's heading
Caa(psi)	Wind resistance coefficient at wind direction
RAA_Total	Total wind resistance
RAA_Self	Wind resistance due to ship itself
RAA	Resistance increase due to wind
Wave_Height_M	Total wave height (measured)
Wave_D_True_M	True total wave direction (measured)
Wave_D_Rel_M	Relative total wave direction (measured)
Wave_Period_M	Total wave period
Swell_Height_W	Swell height (weather data)
Swell_D_True_W	Ture swell direction (weather data)
Swell_D_Rel_W	True swell direction (weather data)
Swell_Period_W	Swell period (weather data)
Sea_Height_W	Sea wave height (weather data)
Sea_D_True_W	Ture sea wave direction (weather data)
Sea_D_Rel_W	Relative sea wave direction (weather data)
Sea_Period_W	Sea wave period (weather data)
seawater_Tempi	Water temperature
Rho_Si	Water density
RAW_Swell_Motion	Added resistance due to swell motion
RAW_Swell_Reflection	Added resistance due to swell reflection
RAW_Swell	Sum of added resistance due to swell
RAW_Sea_Motion	Added resistance due to sea wave motion
RAW_Sea_Reflection	Added resistance due to sea wave reflection
RAW_Sea	Sum of added resistance due to sea wave
RAW	Total added resistance due to waves
RAS	Added resistance due to difference in water density
Delta_R	Total added resistance
eta_Did	Propulsive efficiency coefficient in ideal condition
Xi_P	Load variation coefficient
Rid	Resistance in ideal condition
eta_Dms	Propulsive efficiency coefficient in operating condition
Delp	Amount of power correction
P_Did	Power after correction
Delp_Disp.	Amount of displacement correction
P_Did_Ref	Displacement corrected power

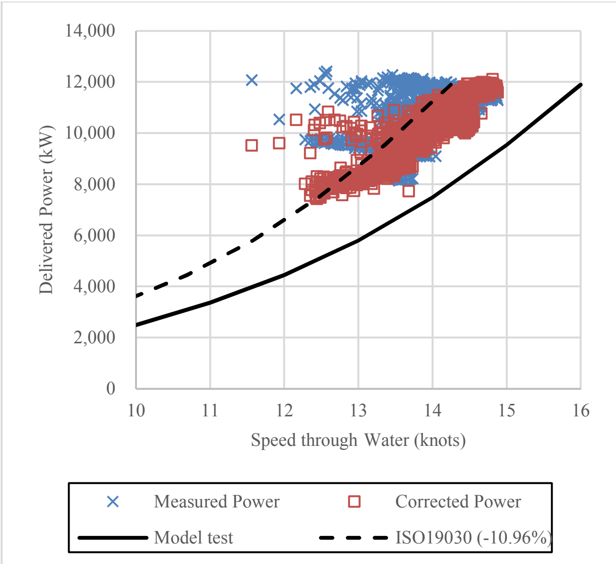

Figure 5: 176K bulk carrier ballast condition results

4. Application

This section describes the application results of the SPA software to the operational data recorded onboard a 176K bulk carrier and an 8600TEU container carrier. Each analysis was performed over one leg of a journey, where the same loading conditions were maintained, and the duration was approximately two to three weeks for the bulk carrier, and several days to a week for the container carrier.

Figure 5 and **Figure 6** show the analysis results of a 176K bulk carrier in ballast and laden loading conditions, respectively. The solid line in the charts represents the model test results. Since ISO19030 results are single values, which represent an averaged decrease in speed from the reference data that are usually the model test results, to make an intuitive visual representation of the results, a dashed line is drawn by shifting the model test curve along the direction of the speed (x) axis by the amount of the averaged Performance Value. In all analysis results, the measured power is corrected to form a line similar to the model test curve and the distance from the model test results to the corrected values, represented by red dots, are how much the performance of the ship has degraded from an as-new condition due to hull fouling, etc.

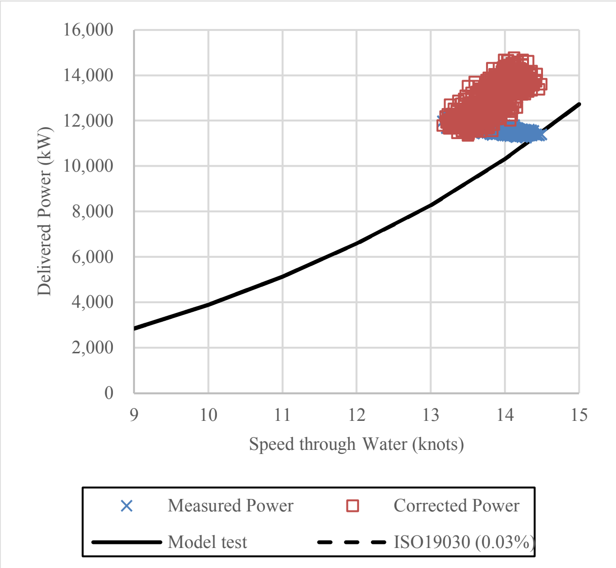

Figure 6: 176K bulk carrier laden condition results

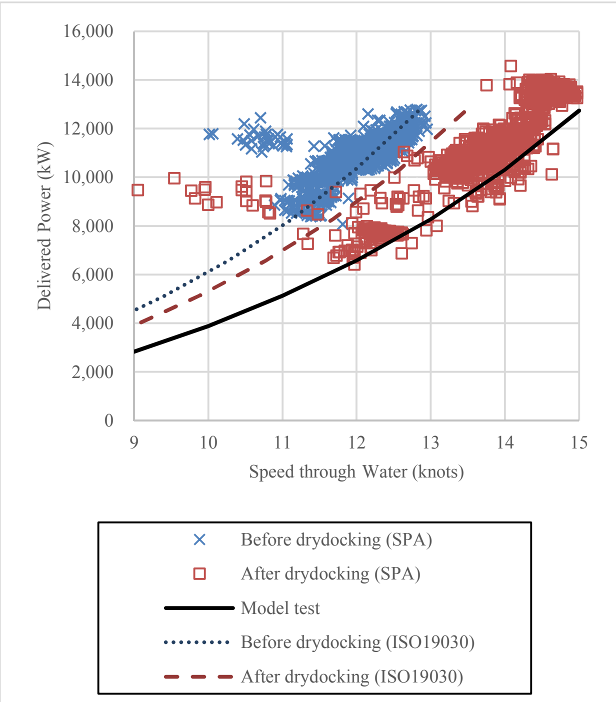

Figure 7: 176K bulk carrier ballast drydocking effects

Figure 7 shows the difference in performance before and after dry-docking. The points represent the analysis results of the method proposed in this paper and the two types of dashed line represent the analysis results using ISO19030. Since ISO19030 relies on averaging out uncorrected environmental effects, at least three months of data is required. Therefore, only the method proposed in this paper can accurately show difference in performance before and after dry-docking with only one leg of a journey before and after. It is clearly shown in **Figure 6** and **Figure 7** where the performance analysis results of the method proposed in this paper significantly differ from those of ISO19030. Please note that ISO19030 analysis results in **Figure 6** are not missing but overlap the model test results.

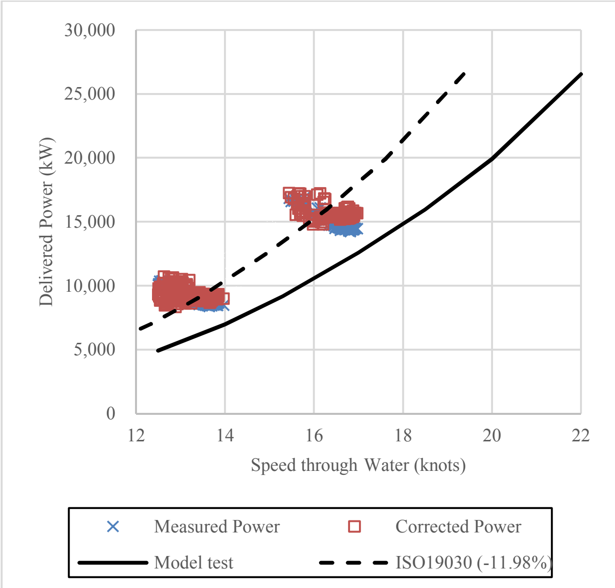

Figure 8: 8600TEU container carrier 80% displacements results

Figure 8 and **Figure 9** shows similar results for the cases of an 8600TEU containers with 80% and 90% displacement conditions. In **Figure 8**, the analysis results using the proposed method and the results using ISO19030 are similar, however this is not the case in **Figure 9**. Thus, there is no guarantee that the proposed method will always give accurate and better analysis results than ISO19030. However the proposed results are more consistent and realistic than ISO19030, where the performance in some cases being only 0.03% different from the model test results (for the 176K bulk carrier laden condition results) or as low as -20% in speed in comparison with the model test results (for the 8600TEU container carrier 90% loading condition results).

Figure 10 shows the dry-docking effects of an 8600TEU container carrier, and the proposed method shows more realistic results than ISO19030, which shows dry-docking has almost no effects.

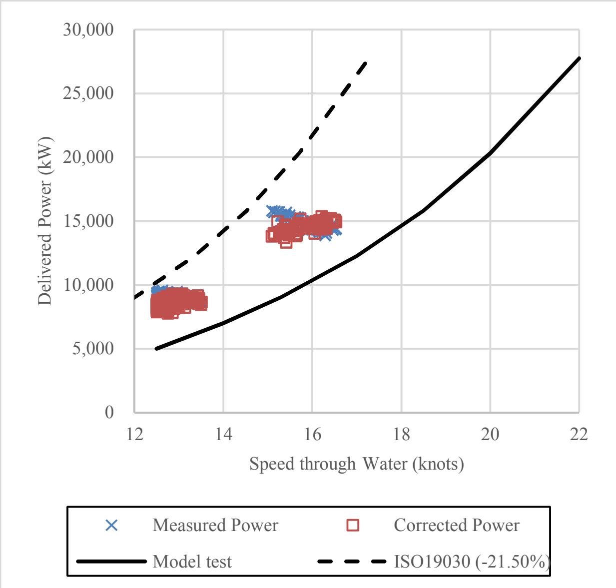

Figure 9: 8600TEU container carrier 90% displacements results

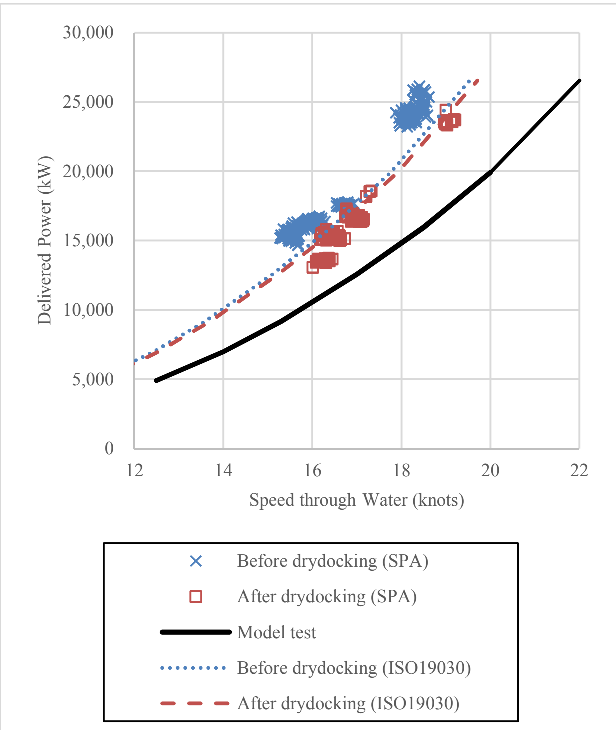

Figure 10: 8600TEU container carrier drydocking effects

5. Conclusions

In this study, a new speed power analysis method based on ISO15016:2015 was proposed. The proposed method first evaluated the added or decreased resistance due to the environmental changes including wind, waves, and water density. Then, the measured shaft power was corrected using the direct power method, and finally, corrected to reference displacement for comparison. The proposed method was implemented in the SPA software, and applied to a 176K bulk carrier and an 8600TEU container carrier. The results show that the proposed method has the following advantages:

① Offers more information than just a value (averaged Performance Value) as in ISO19030.

② Able to provide a more realistic representation of performance than ISO19030, with only a small amount of data, typically with one leg of a journey.

③ Only uses data already collected by ship operators, so that no new data measurements are necessary.

The proposed method and the SPA software that was implemented in this study can be applied to estimate the powering performance of the operating ships used to verify the effects of energy saving devices and low friction paint, which will help decrease fuel consumption and reduce greenhouse gas emissions.

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Author Contributions

Conceptualization, B. J. Park and M. S. Shin; Methodology, B. J. Park, M. S. Shin, and G. J. Lee; Software, B. J. Park and G. J. Lee; Formal Analysis, B. J. Park, M. S. Shin, G. J. Lee, and M. S. Ki; Resources, B. J. Park and M. S. Shin; Data Curation, M. S. Ki; Writing—Original Draft Preparation, B. J. Park; Writing—Review & Editing, B. J. Park; Visualization, B. J. Park; Supervision, M. S. Shin and G. J. Lee; Project Administration, M. S. Shin and M. S. Ki; Funding Acquisition, M. S. Shin;

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