Volume XXV 2022
ISSUE no.2
MBNA Publishing House Constanta 2022

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

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To cite this article: M. G. Manea, E. Manea and C. Militaru, Scientific Bulletin of Naval Academy, Vol. XXV 2022, pg. 8-20.

Submitted: 14.03.2022
Revised: 05.07.2022
Accepted: 25.08.2022

Available online at www.anmb.ro

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-22-I2-001

Factors influencing the period of ship repair works in shipyards and solutions to prognose it

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Abstract. Concerned with the increase of competitiveness and with the obvious aim of maximizing revenues by contracting as many works as possible, a shipyard is interested in estimating the docking time of ships for repair work, to plan the loading of the docks. Total period of repairs work on shipyards and docking period are very difficult to quantify to make an effective estimation due to a significant number of random variables. The authors of this paper appreciate this estimation depends on the content of the technical specification of works received from the beneficiary / owner of the ship and propose a mathematical model based on regression and correlation theory, which could provide a viable solution to meet the need to estimate as efficiently as possible the time required to carry out ship repairs work, as part of the maintenance program imposed by the classification societies. The case studies presented in the paper refer to estimating the duration of the treatment works (exterior and interior) executed on the hull of some ships (oil and bulk tanks) and the influence they have on the total period of repairs work.

shipyards, ship repairs, docking period, regression and correlation theory

1. Introduction

In the most general way, the maintenance / repair study involves the calculation of certain numerical indicators that aim to predict: the probability of uninterrupted function over a period of time; probability of success (proper function); probability of failure (malfunction); average operating time between two faults; average operating time until the first fault; average repair or replacement time [1].

Low reliability and high failure rate lead to high operating costs, which may exceed, under certain conditions, the initial costs estimated for product fabrication. On the contrary, very high reliability and a very low failure rate led to a very significant reduction in operating costs, but also to an exaggerated increase in the price of the respective product [2].

With particular reference to the freight and passenger transport sector, the reliability of the ship (understood as a product) is certified by classification, which is mandatory for all ships.

Most national regulations and especially those applicable in Europe, aims at confirming the strength of the ship's hull construction [3-6]. The classification of a ship also covers superstructures, appendics, machinery and electrical installations, systems and equipments.

The requirements are based on consistent principles, with reference to the type, dimensions and characteristics of the materials used in the construction of the ship, including tests and trials for the safety and reliability of all existing installations, systems and equipment on the ship.

The classification societies (Figure 1) are organized for the purpose of verification during the construction of the ship, in the shipyard, of the processes of design and execution of construction works and also have established requirements, rules for the verification of ships in operation in order to confirm that they are operated and maintained in good technical condition by qualified personnel [3-6].

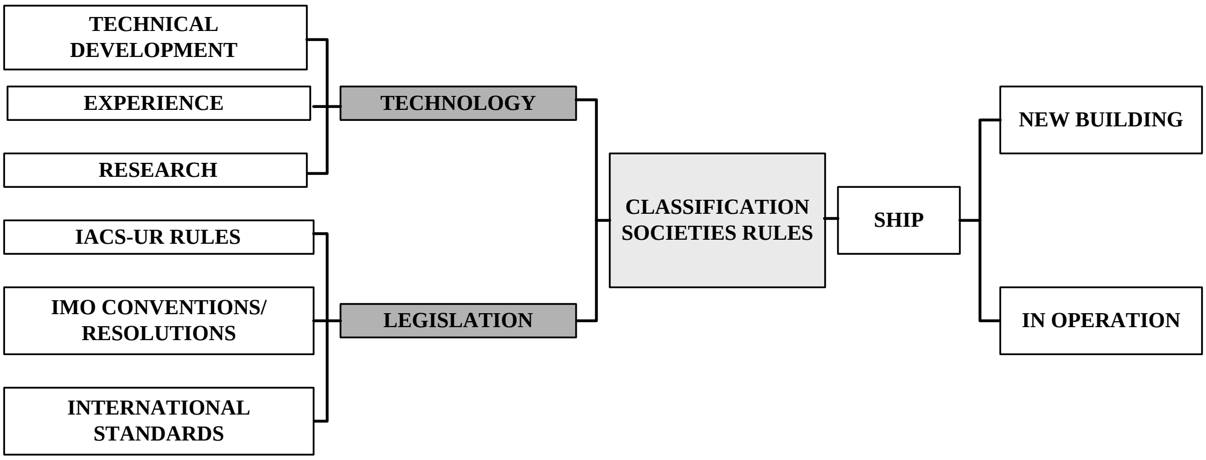


Fig.1. Principles underlying the rules issued by Classification Societies

Inspection and certification of the application of maintenance management systems applied on board of the ships in operation are important because they ensure that the ship is operational and adequate for its functionality, a ship with valid class certificates means that it complies with industry standards and is structurally and mechanically fit to perform its intended purpose [3].

Repair and maintenance operations carried out on a shipyard are correlated with the process of ensuring and managing the resources necessary to carry out the works included in the technical specification.

This process comprises two fundamental approaches [7-8]:

a) strategic: refers to the design of the complex system of maintenance / repair operations of a ship in a shipyard – setting performance requirements; establishing the volume of works; establishing the technologies for the execution of the works; establishing the required number of machinery and equipment; establishing locations for machinery and equipment; establishing the necessary workforce; establishing management and control methods;

b) tactics: ensures the operation of the system at the designed parameters – work planning; management of works; stock management; quality control.

Identifying the variables with significant influence it is of particular importance for the evaluation of the total time period and the docking period necessary for the execution of the repair works mentioned in the technical specification prepared by the owner / technical manager of the ship [9].

2. Theoretical considerations

To evaluate the total time period and the docking period required for the execution of the repair / maintenance works mentioned in the technical specification prepared by the ship's owner / technical manager, it must be taken into account:

- identification of variables with significant influence and their inter-relationship as a result of the estimates made in the bidding and scheduling-planning activities carried out in the shipyards for the execution of the maintenance works of the maritime ships;
- elaboration of a mathematical model suitable for solving the proposed problem.

Probability theory operates with a series of specific notions which, succinctly, are thus presented in the following [10]:

- the experiment is defined as the practical realization of a set of well-specified conditions, according to research criterion;
- the event shall be defined as any result of an experiment, which can be said to have been or not carried out, after the experiment under consideration has been carried out;
- the probability of an event is the ratio between the number of cases favorable to the event and the number of possible cases.

The random variable, if a single measurement is taken, is that quantity which, within an experiment, can take an unknown aprioric value and if a string of measurements is made, it is a notion that gives information on the numerical value of the measured quantity, as well as the frequency of occurrence of a numerical value in a string. If the numerical values of a data string belong to the set of integers or rational numbers, then a discrete random variable is defined, and in the case of belonging of values to the set of real numbers, a continuous random variable is defined [11].

Random variables refer to experiments or phenomena that are governed by statistical laws (when there is a degree of uncertainty about the occurrence of a result or its recurrence) and not deterministic laws (when it is known with certainty what the result will be or not).

Information [12] is increasingly important for organizational performance, because it is: basis of decisions (it is important to reduce the uncertainty in decision making); production factor (information is important to design and market products and services of very high value); simultaneity factor (in the harmonization of the actions of the component units of the enterprise in order to fulfil in the best conditions its overall functions and objectives).

The information necessary to carry out the analysis or predictions of the very complex processes carried out in the repair shipyards, must be of a quantitative nature, to allow the expression in numerical form of the specific characteristics of the analyzed phenomena.

These features can be grouped into six dimensions: content (relevance of data, ease of obtaining values, clarity of definition); the field (degree of coverage, essentiality); level of detail (granularity of attributes, domain accuracy); composition (naturalness, identifiability, homogeneity, minimum required redundancy); consistency (semantic and structural consistency); reaction to change (flexibility and robustness).

Evidence of how the usefulness of a particular process depends on the context refers to the quality of the information - accuracy, completeness, opportunity - as distinct attributes that measure the usefulness of a data set for extracting information necessary for the decision-making process.

Accuracy [12] is generally defined by standard deviation; the range identified within a standard deviation is known as the range $[-cr, +cr]$ and comprises 68.3% of the confidence interval constructed for the results of a measurement. In case of a sufficiently large number of observations / measurements, if the measurement process leads to normally distributed errors, then the true value will be within the range $[-cr, +cr]$ with a probability of 0.683; respectively 0.954 for a range of type $\pm 2cr$ and 0.997 for an interval $\pm 3cr$.

Completeness refers to the degree to which values are present in a data collection and is performed when all values of a variable are recorded. [13].

Opportunity [13] is defined by the possibility of having timely access to complete information; reveals the extent to which the age of the data is adequate for the activity to be performed. The absence of information at the necessary time leads to the postponement of the substantiation of the decision, or to taking it on the basis of insufficient information.

Period of maintenance work on board of a ship in the dock of a shipyard it is part of the maintenance program imposed by the classification societies at predetermined time intervals to confirm that the hull structure, machinery, installations and equipment comply with the applicable requirements and are considered to be in a satisfactory technical condition in compliance with the rules and regulations in force.

The independent variables that are estimated to be considered for the elaboration of a complex mathematical model may be: the age of the ship; the main dimensions of the ship; load capacity; the volume of works to be performed on ships in the dock and / or the quay - presented on locations and types of works, etc.

A linear dependence relation can be established between the time period required for the execution of the maintenance works of the ships in the dock and / or the quay as a dependent variable and the works carried out in the shipyard at the dock and / or the quay considered as independent variables..

The factors influencing the perod of ship repair works in shipyards can be considered as in the following:

- the age of the ship at the time of maintenance work on the dock and on the quay in the shipyard; is expressed in years and is calculated from the date of delivery of the ship in service to the Shipowner;

- the deadweight tonnage of the ship (refers to the maximum cargo capacity of the ship including fuel, oil and water supplies, supplies and payload (including crew and passengers with their luggage) or the mass of all consumable and variable weights on board ship); is expressed in tons;

- the treatment works performed on the exterior body of the ship (refers to the quantity of treatment works performed for the outer body of the ship, in the dockyard); are expressed in square meters;

- the pipeline replacement works and refers to the quantity of pipes replaced at the ship, to the maintenance works carried out in the dock and to the dock, without taking into account the locations and dimensions; are expressed in linear meters;

- the works for replacing the boards, referring to the quantity of board replaced at the ship to the maintenance works carried out in the dock and at the dock; are expressed in kilograms;

-the internal treatment works performed at the ship (refers to the quantity of treatment works performed inside the ship in the dockyard and at the dock); are expressed in square meters.

For the present paper, only two factors were taken into consideration:

$- LTCEx_{ship}$ - represents the treatment works performed on the outer hull of the ship; are expressed in square meters - m², taking into account: location (flat bottom, underwater area, topside and vertical areas); the type of performed work (high pressure fresh water wash; low pressure fresh water wash; air blow; painting – touch up; full coat; sandblasting works, taking into account the applied standards);

$- LTInt_{ship}$ - represents the treatment works performed on the inner hull of the ship; are expressed in square meters - m²; taking into account: location (ballast tanks, cargo tanks, cargo stores, outer decks); the type of performed work (high pressure fresh water wash; low pressure fresh water wash; air blow; painting – touch up; full coat; stripe coat; sandblasting works, taking into account the applied standards)

In the most general way, the variables that could be the basis for the mathematical modelling of the total period of development of the maintenance works of the ships and the docking period at a shipyard, could be selected from the volume of works included in the technical specification prepared by the owner / technical manager of the ship, being accepted relations as:

$$PELM_{ship} = f\left(LTCEX_{ship}\right) \quad (1)$$

$$PELM_{ship} = f\left(LTInt_{ship}\right) \quad (2)$$

The relations (1) and (2) can be written in a form that will follow the determination of the numerical value of the coefficients (b_0, b_1) by applying the multiple linear regression.

$$PELM_{ship} = b_0 + b_1 LTCEX_{ship} \quad (3)$$

$$PELM_{ship} = b_0 + b_1 LTInt_{ship} \quad (4)$$

Relationships (3) and (4) establish a linear dependency between the time required for the execution of the ship maintenance works as a dependent variable and the works carried out in the shipyard considered as independent variables.

3. Case studies

For the case studies presented, a database of ships was used, consisting of 315 bulk carriers and 339 tankers for which maintenance work was carried out at the Constanţa Shipyard. The database was built into an EXCEL software file and, to avoid oversizing this work, the principle of building the database was presented (Table no. 1) without this being presented in detail. For the same reason, in Table no. 2 only the limits (minimum and maximum) of variation of the values of the independent variables are indicated.

Tab. 1. The principle of database construction

SHIP	$LTCEX_{ship}$ [m²]	$LTInt_{ship}$ [m²]
ship no.1	val. 1	val. 1
ship no.2	val. 2	val. 2
ship no.3	val. 3	val. 3
⋮	⋮	⋮
ship no.n	val. n	val. n

Tab.2. Variation limits of independent variables

V_{ship}	Minimum - 1 year Maximum - 44 years old
$LTCEX_{ship}$	Minimum - 0 square meters - m² Maximum – 209 999 square meters - m²
$LTInt_{ship}$	Minimum - 0 square meters - m² Maximum – 98 346 square meters - m²

3.1. Case study for bulk carriers

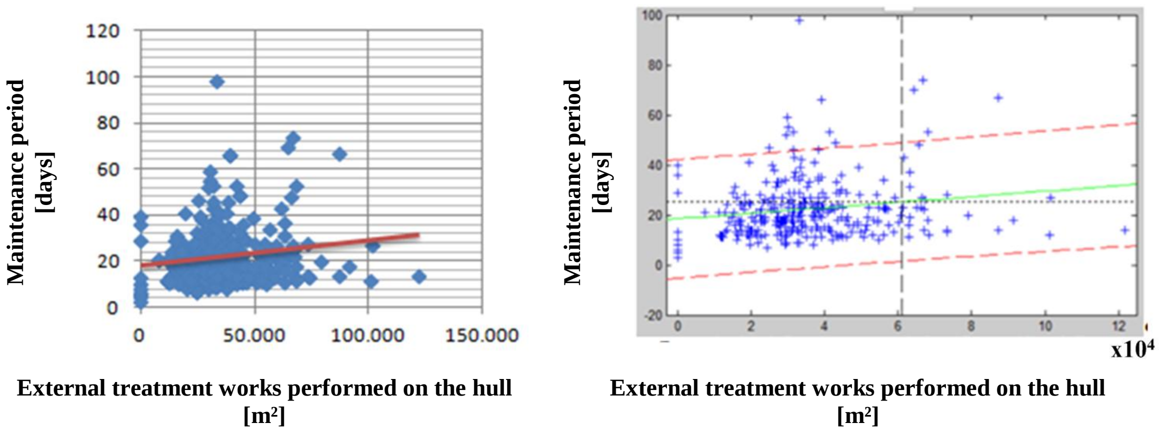


Fig.2. Variation of repair days versus external treatment works performed on the hull Data scatter and interpolation line (left side in EXCEL; right side in MATLAB)

Figure 2 illustrates an inverse linear correlation of the recorded data for the 315 bulk carriers. The analytical expression for the regression function is

$$PELM_{ship} = 18.468 + 10^{-4} LTCEX_{ship} \tag{5}$$

Figure 2 shows that the confidence interval (95%) falls within the upper and lower limits marked on the graph with dotted red lines and indicates a value of +/- 23.69 days of repair compared to the right of interpolation marked in green on the graph. The diagram shows that the estimated value of the

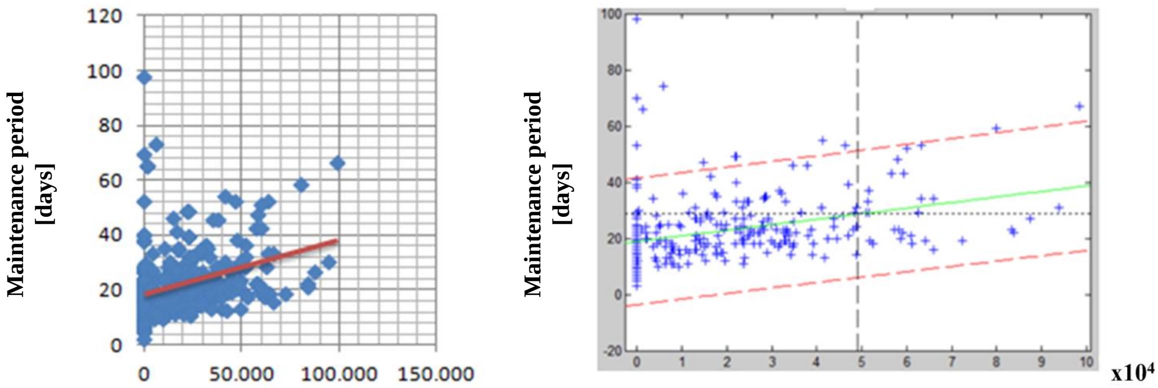
number of repair days is 25.19, if taking into account the treatment work performed on the outer hull of ships included in the database. Table no. 4 presents the numerical results of the analysis.

Tab.4. Results for the variation of repair days versus external treatment works on the bulk carrier's hull

	Regression coefficients	*Standard error*	*the t test*	*probability*
interception	18.66734869	1.513475956	12.33409	9.69E-29
variable $LTCEX_{ship}$	0.000106024	3.83495E-05	2.764683	0.006037

Regression Statistics	
R – Simple correlation coefficient	0.154636662
R^2 – Simple coefficient of determination	0.023912497
R_c^2 – Corrected simple determination coefficient	0.020784012
Standard error	11.98165083
Number of ships entered in the database	315

ANOVA TEST					
	Degrees of freedom	*Variance (sum of squares)*	*Correction dispersion (average of squares)*	*F Statistics*	*Significance threshold*
Regression line	1	1097.296745	1097.297	7.643474	0.00603681
Residual factor	312	44790.70644	143.56		
Total	313	45888.00318			



Internal treatment works performed on the hull [m²] **Internal treatment works performed on the hull [m²]**

Fig.3. Variation of repair days versus internal treatment works performed on the hull Data scatter and interpolation line (left side in EXCEL; right side in MATLAB)

Figure 3 illustrates a direct linear correlation of the recorded data for the 315 bulk carriers. The analytical expression for the regression function is

$$PELM_{ship} = 18.88 + 2 \cdot 10^{-4} LTInt_{ship} \qquad (6)$$

Figure 3 shows that the confidence interval (95%) falls within the upper and lower limits marked on the graph with dotted red lines and indicates a value of +/- 22.59 days of repair compared to the

right of interpolation marked in green on the graph. The diagram shows that the estimated value of the number of repair days is 28.60, if taking into account the treatment work performed on the inner hull of ships. Table no. 5 presents the numerical results of the analysis.

Tab.5. Results for the variation of repair days versus internal treatment works on the bulk carrier's hull

	Regression coefficients	*Standard error*	*the t test*	*probability*	
interception	18.9503785	0.8456385	22.40955065	5.93822E-67	
variable $LTInt_{ship}$	0.00019608	3.103E-05	6.319397244	9.05477E-10	
Regression Statistics					
R – Simple correlation coefficient				0.33685621	
R^2 – Simple coefficient of determination				0.11347211	
R_c^2 – Corrected simple determination coefficient				0.11063067	
Standard error				11.4187479	
Number of ships entered in the database				315	
ANOVA TEST					
	Degrees of freedom	*Variance (sum of squares)*	*Correction dispersion (average of squares)*	*F Statistics*	*Significance threshold*
Regression line	1	5207.0085	5207.008452	39.93478153	9.05477E-10
Residual factor	312	40680.995	130.3878036		
Total	313	45888.003			

3.2. Case study for tankers

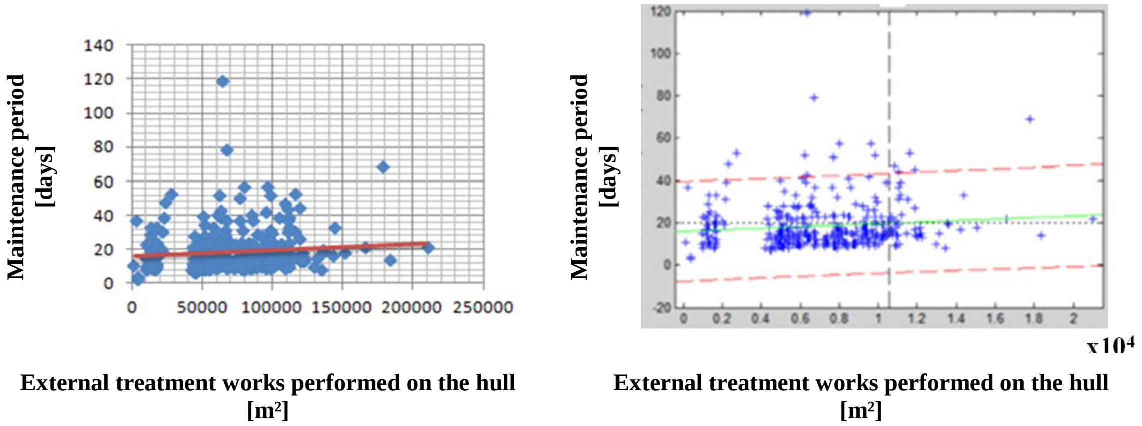


Fig.4. Variation of repair days versus external treatment works performed on the hull Data scatter and interpolation line (left side in EXCEL; right side in MATLAB)

Figure 4 illustrates an inverse linear correlation of the recorded data for the 339 tankers. The analytical expression for the regression function is

$$PELM_{ship} = 16.075 + 4 \cdot 10^{-5} \cdot LTCEX_{ship} \quad (7)$$

Figure 4 shows that the confidence interval (95%) falls within the upper and lower limits marked on the graph with dotted red lines and indicates a value of +/- 23.50 days of repair compared to the

right of interpolation marked in green on the graph. The diagram shows that the estimated value of the number of repair days is 19.88, if taking into account the treatment work performed on the outer hull of ships. Table no. 6 presents the numerical results of the analysis.

Tab.6. Results for the variation of repair days versus external treatment works performed on the tankers hull

	Regression coefficients	*Standard error*	*the t test*	*probability*
interception	16.26703057	1.52724641	10.65121546	5.11033E-23
variable $LTCEX_{ship}$	3.39656E-05	1.93676E-05	1.753733352	0.080387952

Regression Statistics	
R – Simple correlation coefficient	0.095239105
R^2 – Simple coefficient of determination	0.009070487
R_c^2 – Corrected simple determination coefficient	0.006121292
Standard error	11.9147996
Number of ships entered in the database	339

ANOVA TEST

	Degrees of freedom	*Variance (sum of squares)*	*Correction dispersion (average of squares)*	*F Statistics*	*Significance threshold*
Regression line	1	436.6169655	436.6169655	3.07558067	0.080387952
Residual factor	336	47699.38303	141.9624495		
Total	337	48136			

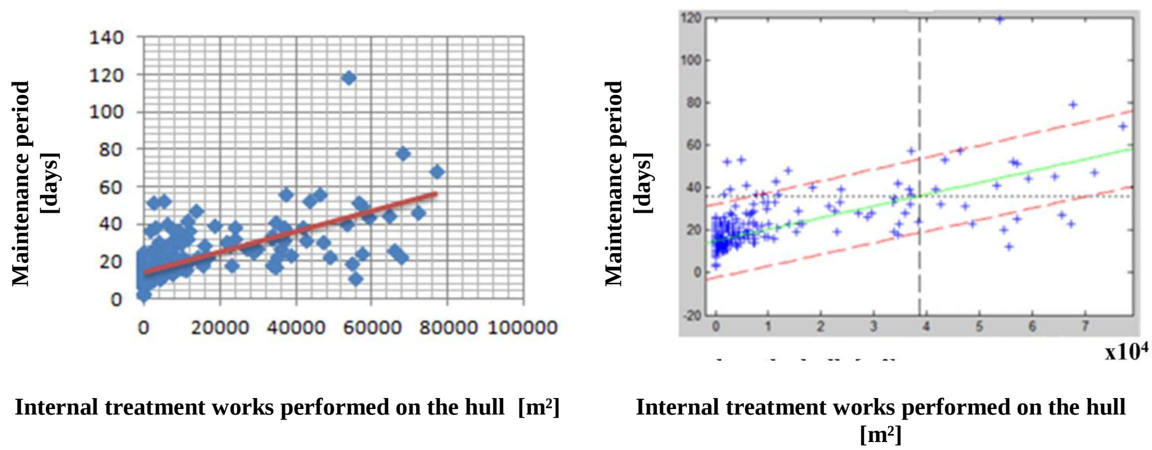


Fig.5. Variation of repair days versus internal treatment works performed on the hull
Data scatter and interpolation line (left side in EXCEL; right side in MATLAB)

Figure 5 illustrates a direct linear correlation of the recorded data for the 339 tankers. The analytical expression for the regression function is

$$PELM_{ship} = 14.848 + 5 \cdot 10^{-4} \cdot LTInt_{ship} \quad (8)$$

Figure 5 shows that the confidence interval (95%) falls within the upper and lower limits marked on the graph with dotted red lines and indicates a value of +/- 17.34 days of repair compared to the

right of interpolation marked in green on the graph. The diagram shows that the estimated value of the number of repair days is 36.03, if taking into account the treatment work performed on the inner hull of ships included in the database. Table no. 7 presents the numerical results of the analysis.

Tab.7. Results for the variation of repair days versus internal treatment works performed on the tankers hull

	Regression coefficients	*Standard error*	*the t test*	*probability*
interception	14.8866748	0.524500353	28.3825829	3.0069E-91
variable $LTInt_{ship}$	0.00054847	3.19655E-05	17.15834736	7.77637E-48

Regression Statistics	
R – Simple correlation coefficient	0.68338319
R^2 – Simple coefficient of determination	0.46701259
R_c^2 – Corrected simple determination coefficient	0.46542632
Standard error	8.73823735
Number of ships entered in the database	339

ANOVA TEST

	Degrees of freedom	*Variance (sum of squares)*	*Correction dispersion (average of squares)*	*F Statistics*	*Significance threshold*
Regression line	1	22480.1179	22480.1179	294.408884	7.77637E-48
Residual factor	336	25655.8821	76.35679196		
Total	337	48136			

3.3. Case study for bulk carriers & tankers

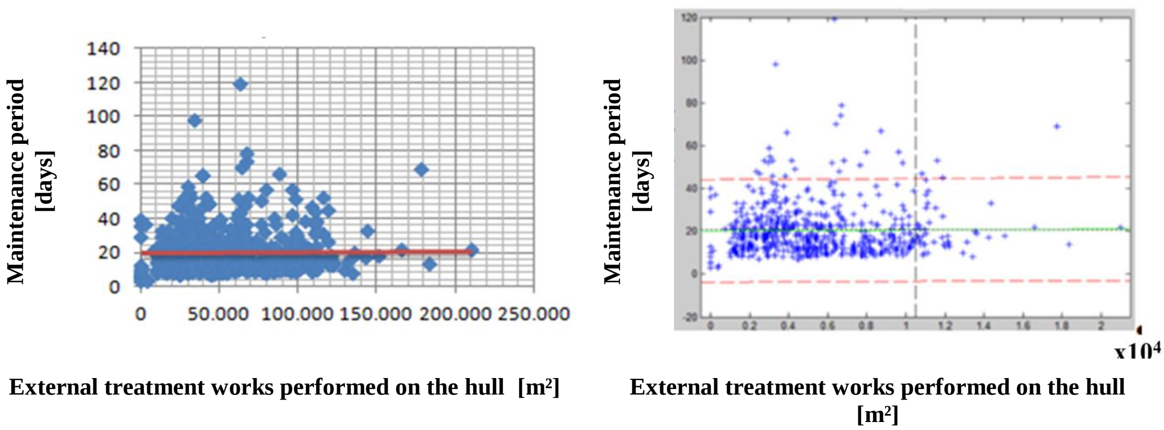


Fig.6. Variation of repair days versus external treatment works performed on the hull Data scatter and interpolation line (left side in EXCEL; right side in MATLAB)

Figure 6 illustrates an inverse linear correlation of the recorded data for the 654 bulk carriers & tankers. The analytical expression for the regression function is

$$PELM_{ship} = 20{,}206 + 4 \cdot 10^{-6} \cdot LTCEX_{ship} \quad (9)$$

Figure 6 shows that the confidence interval (95%) falls within the upper and lower limits marked on the graph with dotted red lines and indicates a value of +/- 23.98 days of repair compared to the right of interpolation marked in green on the graph. The diagram shows that the estimated value of the

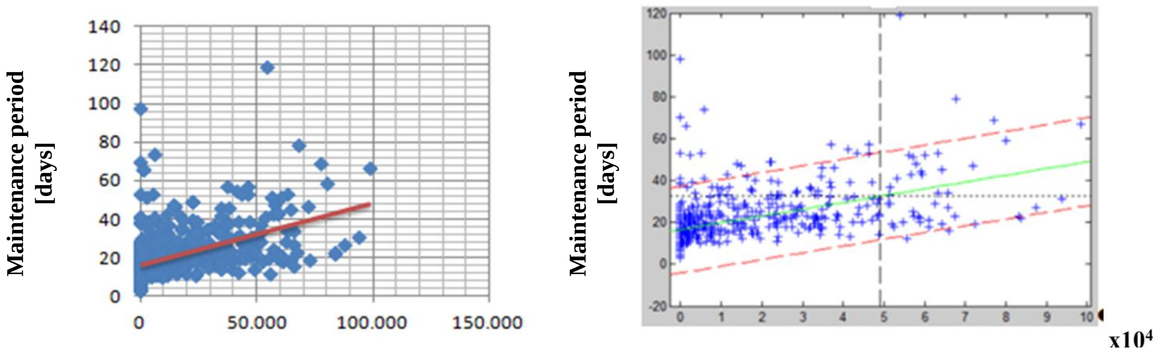
number of repair days is 20.65, if taking into account the treatment work performed on the outer hull of ships. Table no. 8 presents the numerical results of the analysis.

Tab.8. Results for the variation of repair days versus external treatment works on the combined hulls

	Regression coefficients	*Standard error*	*the t test*	*probability*
interception	20.28773764	0.922977872	21.9807411	1.60095E-80
variable $LTCEX_{ship}$	3.15421E-06	1.46531E-05	0.215259208	0.829632651

Regression Statistics	
R – Simple correlation coefficient	0.008436373
R^2 – Simple coefficient of determination	7.11724E-05
R_c^2 – Corrected simple determination coefficient	-0.001464817
Standard error	12.17759145
Number of ships entered in the database	654

ANOVA TEST					
	Degrees of freedom	*Variance (sum of squares)*	*Correction dispersion (average of squares)*	*F Statistics*	*Significance threshold*
Regression line	1	6.871416512	6.871416512	0.046336527	0.82963265
Residual factor	651	96539.22047	148.2937334		
Total	652	96546.09188			



Internal treatment works performed on the hull [m²] **Internal treatment works performed on the hull [m²]**

Fig.7. Variation of repair days versus internal treatment works performed on the hull
Data scatter and interpolation line (left side in EXCEL; right side in MATLAB)

Figure 7 illustrates a direct linear correlation of the recorded data for the 654 bulk carriers & tankers. The analytical expression for the regression function is

$$PELM_{ship} = 16{,}52 + 3 \cdot 10^{-4} \cdot LTInt_{ship} \quad (10)$$

Figure 7 shows that the confidence interval (95%) falls within the upper and lower limits marked on the graph with dotted red lines and indicates a value of +/- 20.79 days of repair compared to the right of interpolation marked in green on the graph. The diagram shows that the estimated value of the

number of repair days is 32.48, if taking into account the treatment work performed on the outer hull of ships. Table no. 9 presents the numerical results of the analysis.

Tab.9. Results for the variation of repair days versus internal treatment works on the combined hulls

	Regression coefficients	*Standard error*	*the t test*	*probability*
interception	16.5428338	0.491373654	33.66650541	1.123E-144
variable $LTInt_{ship}$	0.000324156	2.20518E-05	14.69978018	1.89015E-42

Regression Statistics	
R – Simple correlation coefficient	0.499206659
R^2 – Simple coefficient of determination	0.249207289
R_c^2 – Corrected simple determination coefficient	0.248053997
Standard error	10.55205094
Number of ships entered in the database	654

ANOVA TEST

	Degrees of freedom	*Variance (sum of squares)*	*Correction dispersion (average of squares)*	*F Statistics*	*Significance threshold*
Regression line	1	24059.98977	24059.98977	216.0835372	1.89015E-42
Residual factor	651	72486.10211	111.345779		
Total	652	96546.09188			

4. Conclusions

The purpose of the modelling is to provide the management of the shipyard the opportunity to improve their organizational performance on the estimation of the duration of retaining of ships in the docks, which offers a relatively high degree of safety for making the decisions necessary to optimize the internal processes for carrying out maintenance work.

The results of the case studies are summarized in Table no. 10 in which are presented the values obtained for R^2 – simple coefficient of determination and R – simple correlation coefficient.

Simple correlation coefficient, R, has values between 0 (if there is no link between the dependent variable and the independent variables) and 1 (if there is a perfect functional connection).

Simple coefficients of determination, R^2, which is the square of the simple correlation coefficient, shows the proportion of the total variation of the dependent variable, which is explained by the independent variables.

In economic practice, it is considered that a simple correlation is strong enough if the value of the coefficient of determination is greater than 0,7 (or 70%, in percentage terms).

Tab.10. The results for the case studies

	R^2			R		
	bulk carriers	tankers	combined	bulk carriers	tankers	combined
$PELM_{ship} = f(LTCEX_{ship})$	0.0239	0.0090	0.00007	0.154	0.0952	0.0084
$PELM_{ship} = f(LTInt_{ship})$	0.1134	0.4670	0.2492	0.336	0.6833	0.4992

Interpretation of the results leads to the conclusion that the analysis based on a single independent variable cannot be considered satisfactory, the values of the simple coefficient of determination, R^2, being small, which shows that the ship maintenance period ($PELM_{ship}$) in the shipyard, it depends on many factors, each one contributing in a certain proportion, quite small. Therefore, it is necessary to take into account, simultaneously, several independent variables, going up to 9 to obtain satisfactory results [14-17].

To ensure the validity and usefulness of regression functions results from the analysis of a database, the quality of the technical specification is a fundamental factor. The advantage of a quality technical specification, consists in limiting the possibility of the appearance of orders for additional works, thus, there is a good chance that the initially estimated period will be respected, shipyard and ship costs are also likely to be kept within the budgets initially set.

Additional works during the execution of works for maintenance, upkeep and improvements on board the ship in the shipyard, cannot be excluded, considering that when checking the condition of the hull and the structure of the ship in dock, after measuring the thickness of the steel sheets, the appearance or evolution of the corrosion of the bottom sheets of the ship can be identified and also, any deformations, ruptures or other damage to the hull structure may be identified.

For the shipyard, the additional works have a negative influence, due to the need to supplement the workforce to cover the additional volume of works commissioned for the ongoing project and due to immobilization of technical capabilities over the estimated term, thus existing there a major risk of being negatively affected the development of other projects undertaken during that period.

For the owner / technical manager of the ship, additional work has a negative influence, due to additional costs necessary to cover the additional volume of ordered works and due to the ship's detention period being exceeded, and due to the expiration of the period that may have a negative influence on the further development of the commercial obligations assumed by the ship detention of the ship.

Acknowledgements

Thanks to Constanta Shipyard for permission to use information from the portfolio of vessels for which performed repair work.

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