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Using regression theory to solve some problems regarding ship repairing and maintenance activities in shipyards

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Abstract. The owners will always try to reduce the ships maintenance works timeframe clearly aimed at reducing the period during which the ship has no income. In turn, the shipyard also will try to reduce the timeframe for the maintenace works carried out on board of the drydocked ships and alongside berths, clearly aimed at revenue maximizing by contracting a larger number of ships for drydocking. The objective was to find a method (using regression theory) for the ships drydocking and/or berthed maintenance works carried out in the shiprepairs shipyards time frame that exploits the information held by the shipyard in their maintenance and repairs works portfolio performed for various customers over time.

1. Introduction

The experience of the shipyards has concluded that the total period of maintenance work due on board a ship and the period of docking are very difficult to quantify for an efficient forecast, due to a significant number of random variables.

The period of maintenance work on board a ship in the dock or at the quay of a shipyard is part of the maintenance program imposed by the classification societies at predetermined time intervals to confirm that the body structure of the ship, the machines, the installations and the equipment comply with the applicable requirements and are considered to be in a satisfactory technical condition respecting the norms and regulations in force. The terms referring to the repair and maintenance of the ship have different connotations in the specialized literature [1] [2] [3] [4]. On the one hand, the repair of a ship consists of actions to correct a malfunction in the structure of the body of the ship, cars, equipment or systems existing on board. On the other hand, the maintenance of a ship involves all the activities carried out on board or in the dock to prevent potential failures. To perform, both activities require the same infrastructure, of a shipyard, so the terms of repair and maintenance of the ship are used together (R&M) and involve the action of docking the ship to perform a standard maintenance routine..

2. Theoretical aspects

During the documentation, it was found that various authors have elaborated studies, especially regarding the minimization of the operating costs of the ships and the maintenance costs of the ships [5] [6] [7].

From the documentation made by the authors of this paper, it was found that there is insufficient information regarding the analysis, modeling and forecasting of the total period of maintenance work of the ships and of the docking period in a shipyard, although there are researchers [8] concern about this topic.

The conclusion is that modelling must be preceded by:

- knowledge of the operational structure of a shipyard for ship repair;
- knowledge of the works to be performed at the docked ship;
- identification of the number of variables with significant influence and their interrelation.

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.

Based on the studies and researches carried out, the authors followed the analysis of the validity and the opportunity to use the following function (for the proper functioning of the simulation program, it is preferred to keep the symbolization of the terms in Romanian):

$$\mathrm{PELM}_{\mathrm{Navă}} = \mathrm{f}(\mathrm{V}_{\mathrm{Navă}},\quad \mathrm{TDW}_{\mathrm{Navă}},\quad \mathrm{LTCEX}_{\mathrm{Navă}},\quad \mathrm{LITub}_{\mathrm{Navă}},\quad \mathrm{LITable}_{\mathrm{Navă}},\quad \mathrm{LTInt}_{\mathrm{Navă}}) \qquad (1)$$

Thus, a linear dependence relation is 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 work carried out in the shipyard at the dock and / or the quay considered as independent variables..

The meaning of the terms involved in the relationship (1) is specified in the following:

$\mathrm{PELM}_{\mathrm{Navă}}$ represents the period of performing the maintenance work of the ship at the dock and at the quay in the shipyard; is expressed in number of days from the date of entry of the ship in the shipyard until the completion of the maintenance work and the departure date of the ship from the shipyard;

$\mathrm{V}_{\mathrm{Navă}}$ represents 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;

$\mathrm{TDW}_{\mathrm{Navă}}$ represents 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;

$\mathrm{LTCEX}_{\mathrm{Navă}}$ represents 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;

$\mathrm{LITub}_{\mathrm{Navă}}$ represents 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;

$\mathrm{LITable}_{\mathrm{Navă}}$ represents 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;

$\mathrm{LTInt}_{\mathrm{Navă}}$ represents 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.

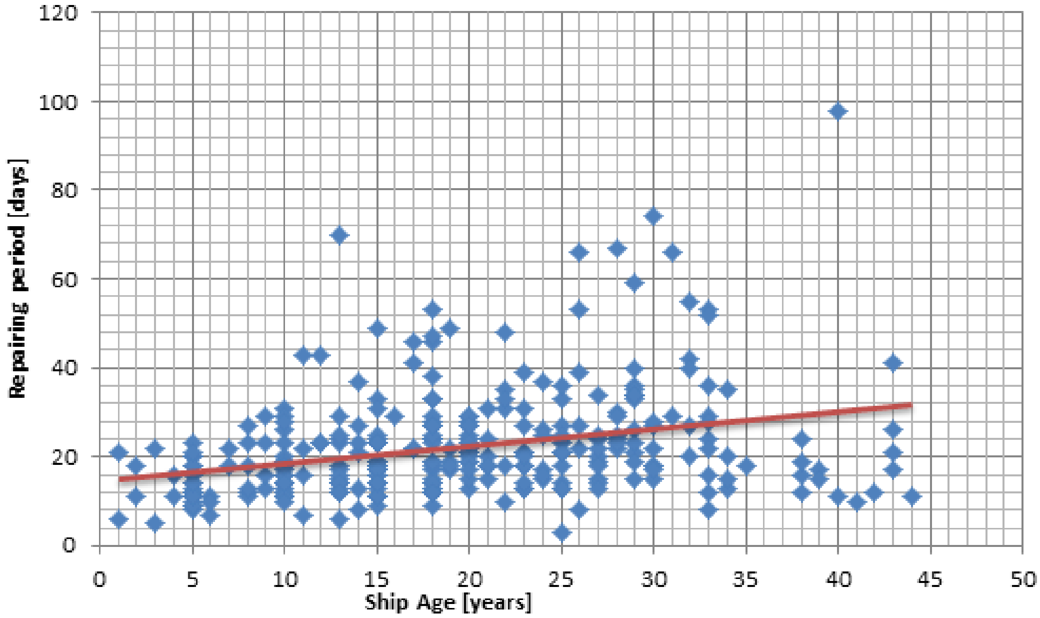
The relation (1) can be written in the form (2) in which the numerical value of the coefficients ($b_0,\quad b_1,\quad b_2,\quad b_3,\quad b_4,\quad b_5,\quad b_6$) will be determined by applying multiple linear regression.

$$PELM_{Navă} = b_0 + b_1 V_{Navă_i} + b_2 TDW_{Navă_i} + b_3 LTCEX_{Navă_i} +$$
$$+ b_4 LITub_{Navă_i} + b_5 LITable_{Navă_i} + b_6 LTInt_{Navă_i} \qquad (2)$$

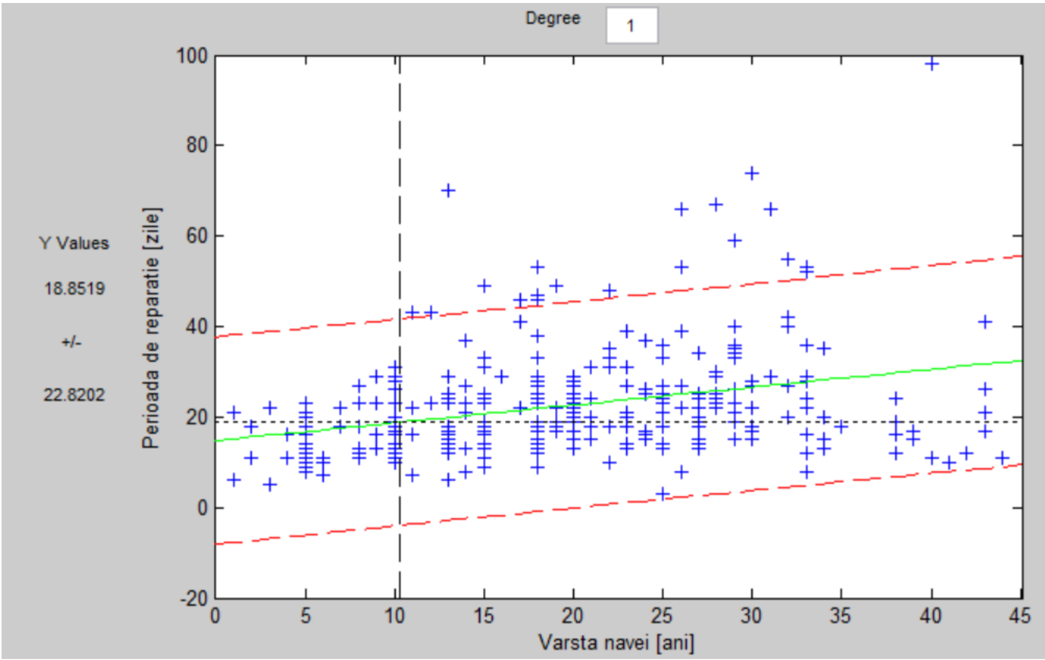
where $b_0,\quad b_1,\quad b_2,\quad b_3,\quad b_4,\quad b_5,\quad b_6$ are the regression coefficients; $i = 1,2,3,\dots,n$ represents the number of ships in which maintenance work has been carried out on a shipyard.

3. Case Studies

The following is the case study for the 315 bulk carrier vessels.



1. a)



1. b)

Fig.1. Variation of the repair days according to the age of the vessels
Data dispersion and interpolation line a) in EXCEL; b) in MATLAB]

Figure 1 a) and b) illustrate a direct linear correlation of the data recorded for the 315 bulk carrier vessels. The analytical expression of the regression function is

$$PELM_{Navă} = 14{,}806 + 0{,}3928V_{Navă} \tag{3}$$

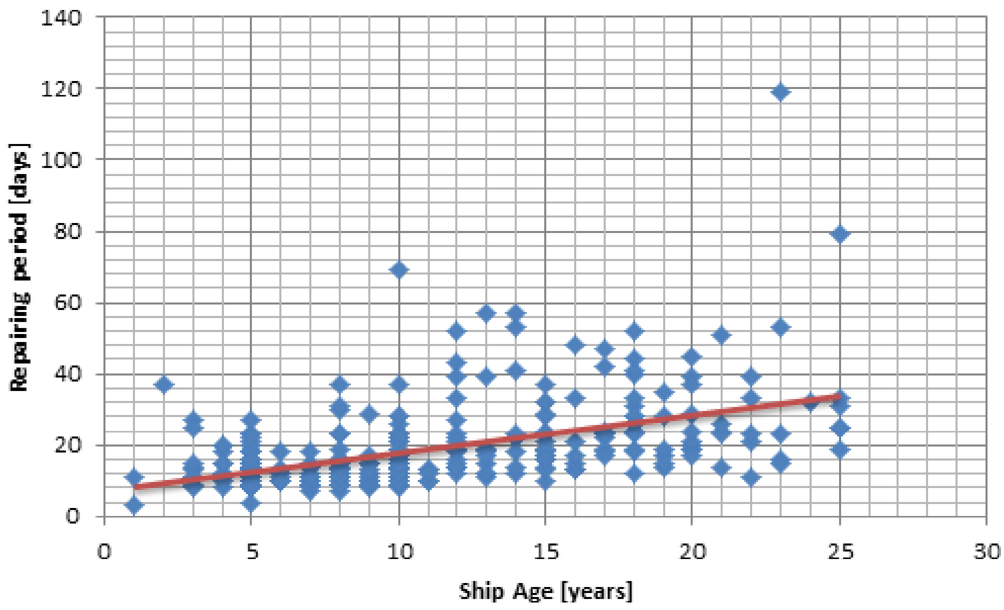
From Figure 1 b) it is observed that the confidence interval (95%) falls within the upper and lower limits marked on the graph with red dotted lines and indicates a value of +/- 22.82 days of repair against the marked interpolation line with green on the graph. From the diagram it is observed that the predicted value (marked on the graph with black dotted line - cursor target) of the value regarding the number of days of repair is 18.85 days, if the age of the vessels included in the database is taken into account.

	Regression coefficients	Standard error	Test t	Probability
Interception	14.9530136	1.494104237	10.00801	1.25E-20
Variabile x_1 $V_{Navă}$	0.386747107	0.069691201	5.54944	6.13E-08

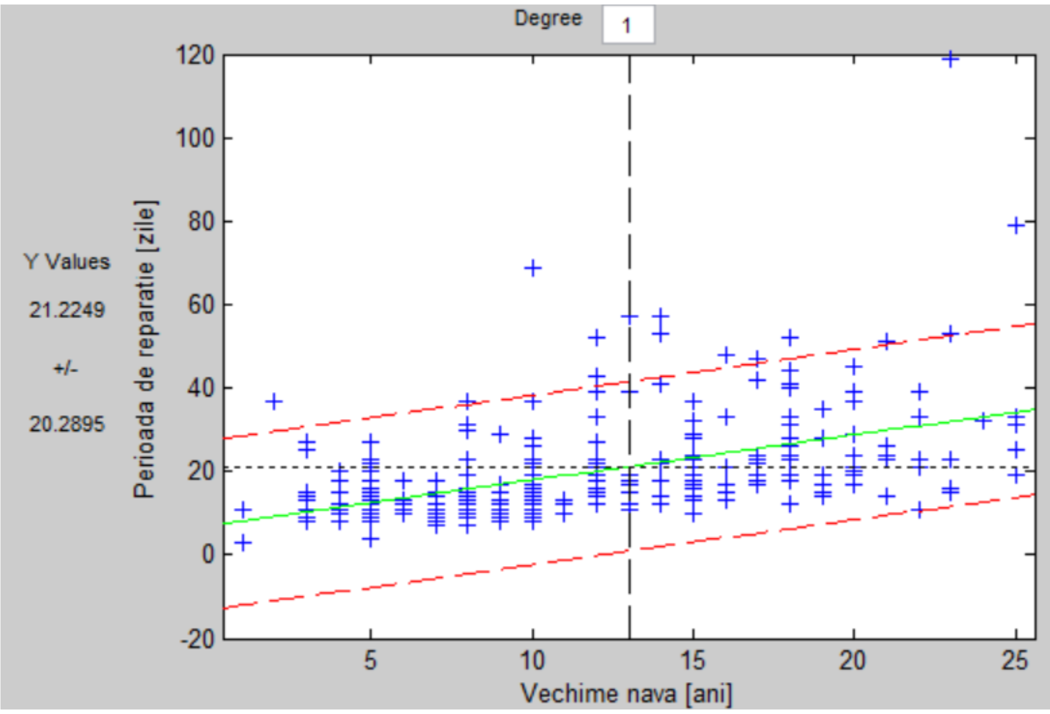
Regression Statistics	
R – Simple correlation coefficient	0.299730595
R^2 – Simple coefficient of determination	0.08983843
R_c^2 – Corrected coefficient of simple determination	0.086921245
Standard error	11.56995128
The number of ships that entered the database	315

ANOVA TEST					
	The degrees of freedom	Variance (sum of squares)	The corrected dispersion (mean of squares)	Statistics F	Significance threshold for statistics F
Regression line	1	4122.50615	4122.506	30.79628	6.12679E-08
Residual factor	312	41765.49703	133.8638		
Total	313	45888.00318			

The following is the case study for the 339 tank-type vessels.



2. a)



2. b)

Fig.2. Variation of the repair days according to the age of the vessels
Data dispersion and interpolation line a) in EXCEL; b) in MATLAB]

Figure 2 a) and b) illustrate a direct linear correlation of the data recorded for the 339 tank-type vessels. The analytical expression of the regression function is

$$PELM_{Navă} = 7{,}1577 + 1{,}0821 \cdot V_{Navă} \tag{4}$$

From Figure 2 b) it is observed that the confidence interval (95%) falls within the upper and lower limits marked on the graph with red dotted lines and indicates a value of +/- 20.28 days of repair against the marked interpolation line with green on the graph. From the diagram it is observed that the predicted value (marked on the graph with a black dotted line - cursor target) of the value regarding the number of days of repair is 21.22 days, taking into account the age of the vessels included in the database..

	Regression coefficients	Standard error	Test t	Probability
Interception	7.230846128	1.196300211	6.04434076	3.98737E-09
Variabile x_1 $V_{Navă}$	1.077600559	0.099374702	10.84381172	1.08097E-23

Regression statistics	
R – Simple correlation coefficient	0.509156238
R^2 – Simple coefficient of determination	0.259240075
R_c^2 – Corrected coefficient of simple determination	0.257035432
Standard error	10.30158618
The number of ships that entered the database	339

ANOVA TEST					
	The degrees of freedom	Variance (sum of squares)	The corrected dispersion (mean of squares)	Statistics F	Significance threshold for statistics F
Regression line	1	12478.78026	12478.78026	117.5882527	1.08097E-23
Residual factor	336	35657.21974	106.1226778		
Total	337	48136			

4. Conclusions

The analysis of the presented data leads to the following findings:

a) the analysis based on a single independent variable, cannot be considered satisfactory, the values of the simple determination coefficient, R^2, being small:

- between 0.013 and 0.495 for bulk carriers
- between 0.001 and 0.555 for tanks
- between 0.00007 and 0.385 for the combined study (bulk carriers and tanks)

which shows that the period of maintenance work of the ship ($PELM_{Navă}$) at the dock and at the quay in the shipyard, depends on many factors, each, in part, contributing in a certain proportion, quite small;

b) the values of the multiple determination coefficient, R^2, increase as more independent variables are considered in the analysis

- for bulk vessels from 0.119 for two independent variables to 0.636 for nine independent variables;
- for tanks from 0.272 for two independent variables to 0.780 for nine independent variables;
- for the combined study from 0.167 for two independent variables to 0.645 for nine independent variables;

what strengthens the previous finding, namely that the Period of Maintenance Works of the Ship ($PELM_{Navă}$) at the dock and at the quay in the shipyard, depends on many factors that must be considered;

c) the regression function valid for the bulk carrier vessels

$$\begin{aligned}
PELM_{Navă} &= 9{,}973 + 0{,}165V_{Navă} - 2{,}49 \cdot 10^{-5}TDW_{Navă} + \\
&+5{,}695 \cdot 10^{-5}LTCEX_{Navă} + 5{,}77 \cdot 10^{-3}LITub_{Navă} + \\
&+8{,}652 \cdot 10^{-5}LITable_{Navă} - 1{,}871 \cdot 10^{-6}LTInt_{Navă} + \\
&+4{,}495 \cdot 10^{-4}LSAL_{Navă} + 1{,}046 \cdot 10^{-2}LTkCV_{Navă} + \\
&+4{,}33 \cdot 10^{-3}LTkCS_{Navă}
\end{aligned} \quad (5)$$

d) regression function valid for tank vessels

$$\begin{aligned}
PELM_{Navă} &= 7{,}82 + 0{,}305V_{Navă} - 2{,}99 \cdot 10^{-6}TDW_{Navă} - \\
&- 1{,}19 \cdot 10^{-5}LTCEX_{Navă} + 8{,}003 \cdot 10^{-3}LITub_{Navă} + \\
&+1{,}91 \cdot 10^{-4}LITable_{Navă} + 1{,}74 \cdot 10^{-4}LTInt_{Navă} + \\
&+ 1{,}71 \cdot 10^{-3}LSAL_{Navă} + 2{,}404 \cdot 10^{-5}LTkCV_{Navă} + \\
&+ 1{,}21 \cdot 10^{-3}LTkCS_{Navă}
\end{aligned} \quad (6)$$

e) regression function valid for the combined study of bulk and tank vessels

$$\begin{aligned}\mathrm{PELM_{Navă}} &= 8{,}253 + 0{,}215\mathrm{V_{Navă}} - 2{,}11 \cdot 10^{-5}\mathrm{TDW_{Navă}} + \\ &+ 4{,}316 \cdot 10^{-5}\mathrm{LTCEX_{Navă}} + 7{,}808 \cdot 10^{-3}\mathrm{LITub_{Navă}} + \\ &+ 8{,}593 \cdot 10^{-5}\mathrm{LITable_{Navă}} + 6{,}425 \cdot 10^{-5}\mathrm{LTInt_{Navă}} + \\ &+ 5{,}014 \cdot 10^{-4}\mathrm{LSAL_{Navă}} + 7{,}755 \cdot 10^{-3}\mathrm{LTkCV_{Navă}} + \\ &+ 4{,}938 \cdot 10^{-3}\mathrm{LTkCS_{Navă}}\end{aligned} \tag{7}$$

f) in the study for nine independent variables, it is found that the values of the multiple determination coefficient, R^2, are:

- 0,636 for the bulk carrier vessels
- 0,780 for the tank vessels
- 0,645 for the combined study of bulk and tank vessels

the explanation can be found in the way of drawing up the Technical Specification of the Works (more superficial in the case of bulk carriers, more complete and more correct in the case of tanks).

In view of the above findings and starting from the premise that each shipyard has unique organizational and functional structures, in order to improve the organizational performance by predicting the duration of the maintenance work of the maritime ships in the repair sites, the following recommendations can be made:

- Request from the Ship Owner / Technical Manager of a Technical Specification of Works as correct and complete as possible.
- The use, in analyzes, of distinct databases, built on functional and constructive types of ships.
- The use, in analyzes, of its own portfolio of ships for which maintenance work was carried out in the dock and / or at the quay.
- Implementation of a computerized database management system from its own portfolio, in order to update, in real time, the equations for forecasting the duration of the maintenance work of the maritime vessels in the repair sites.

The contributions of the authors (theoretical and applicative) regarding the improvement of the organizational performance of the shipyards of repair, crystallized in a number of works published over time, with different occasions [9] [10] [11] [12].

Acknowledgements
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