Modelling of maritime ship repairs processes in shipyards, using the linear regression and correlation theory

M G Manea¹, R Zăgan² and E Manea³
¹Ovidius University of Constanta, Department of Marine Engineering, Mamaia Ave., No.124, Constanta, RO
²Maritime University of Constanta, Electromechanics Faculty, Department of Engineering Science, Mircea cel Batran Str., No.104, Constanta, RO
³Constanta Shipyard, Greece Branch Office, Port Str., No.1, Constanta, RO
E-mail: mihaelagretimanea@gmail.com

Abstract. The tendering and programming-planning activities carried out in the shipyards for the execution of the repair works of the maritime vessels are the result of estimates that operate with fixed data, conditioned by variables belonging to a wide spectrum of conditions and limitations. In the documentation made for the elaboration of the present work and the resolution of the chosen research topic, the studies were directed to the fundamental theoretical fields of: probabilities and statistics; modelling and numerical simulations. The objective assumed by the authors was to find a well-founded method for estimating the retention period of the ship in the shipyard, to exploit the information held in the portfolio of repair works performed to various clients, over time. This gives the perspective of optimizing the decisions of the shipyard management with reference to the problem of anticipating and programming the duration of the repair works of the maritime vessels. The purpose of the research consists in proposing an analytical function for analyzing the linear dependence of the time period, as a dependent variable, on the works carried out in the shipyard, considered as independent variables. The role and importance of the technical specification of the works prepared by the owner/technical manager of the ship, from the perspective of the management of the repair works of the maritime vessels in a repair yard, are highlighted, as well as the importance of the selection of variables with significant influence in the forecast of the duration of the repair works of the maritime vessels in a shipyard.

1. Introduction
Without claiming to have a complete knowledge of the contributions made, over time, by various authors, on the subject of interest, it was found, during the documentation, that the analyzed studies refer, in particular, to the minimization of the operating costs of the ships and ship maintenance costs (depending on the evolution of the maritime transport market and the evolution of fuel prices) [1-7].

From the research which was made, it was found that there is insufficient information regarding analysis, modeling and forecasting of the total period of ship maintenance works and of the docking period in a shipyard, the most probable explanations being:

- lack of a proper database to the construction of a mathematical model (shipyards do not have public databases, obviously for competitive reasons, but also for other reasons, such as: the large volume of data, the difficulties of correlating these data in order to build a mathematical model, financial efforts and difficulties in managing the database to have customized software.
available – Enterprise Resources Program – ERP; it should be borne in mind that, although it carries out similar activities – new constructions and / or repairs – shipyards are so different from each other, for so many different reasons, that only custom software can effectively respond to their needs);

- the difficulties of systematizing, in a coherent mathematical model, the volume of works mentioned in the Technical Specification (the volume of work depends on the type of maintenance applied on board of the ships, so that they comply with the requirements of the classification society and the requirements of the equipment manufacturers);
- the difficulties encountered in establishing the number of variables that significantly influence the time parameter (the total duration of the maintenance works and the period of docking, possibly also of anchoring at the quay) and which should be taken into account in substantiating the mathematical model;
- difficulties related to the analytical systematization of the interrelation of variables (the variables that determine the total duration of the maintenance works and the docking period influence each other, in a random way, depending on the findings made during the works and lead to changes – sometimes significant – in the volume of works in the Technical Specification);
- quantification of the consequences induced into result of the estimates carried out in the bidding and programming-planning activities carried out by the shipyards for the execution of the maintenance works of the maritime ships, for the evaluation of the total period of time and of the docking period, necessary for the execution of the volume of works mentioned in the Technical Specification drawn up by the Owner / Technical Manager of the ship;
- developing a satisfactory mathematical model (considering the random evolution of the variables involved in the process) for the estimation of the total period of time in which the ship is stationed in the shipyard and of the docking period necessary for the execution of the volume of works mentioned in the Technical Specification drawn up by the Owner / Technical Manager of the ship.

There are also authors [8] concerned with the development of an efficient mathematical model for the analysis, modeling and forecasting of the total period of ship maintenance work and of the docking period in a shipyard.

In time, the authors of the present paper, have made some contributions to solving the issue under discussion, proving a constant concern about this topic [9-13]. The conclusion is that the modelling process must necessarily be preceded by:

- knowledge of the operational structure of a ship repair yard. That must include, in its content, only the essential elements, which must not be missing from any shipyard carrying out repair work for maritime vessels. (detailed knowledge of the operational structure of the shipyard in which maintenance works are to be performed for maritime ships, directly influences the construction of the mathematical model, allowing the particular identification of the variables to be taken into account in the modeling process).
- knowledge of the work to be carried out on the docked ship and, if applicable, of the work carried out on the quay (the difficulty of mathematical modeling is generated by the fact that, during the course of the works, it may happen that additional works appear that need to be executed and that are very difficult to anticipate, in many cases).
- identifying the number of variables with significant influence and their inter-relationship. In the most general way, the variables that could underlie the mathematical modeling of the total period of ship maintenance work and of the docking period in a shipyard, could be selected from the Volume of Works included in the Technical Specification prepared by the Owner / Technical Manager of the ship.

2. Some theoretical aspects
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):

$$ PELM_{Nav} = f(V_{Nav}, \ \text{TDW}_{Nav}, \ \text{LTCEX}_{Nav}, \ \text{LITub}_{Nav}, \ \text{LITab}_{Nav}, \ \text{LTInt}_{Nav}) \quad (1) $$

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:

- $PELM_{Nav}$ 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;
- $V_{Nav}$ 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 Ship Owner;
- $\text{TDW}_{Nav}$ 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;
- $\text{LTCEX}_{Nav}$ 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;
- $\text{LITub}_{Nav}$ 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;
- $\text{LITab}_{Nav}$ 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;
- $\text{LTInt}_{Nav}$ 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 equation (1) can be written in the form (2) in which the numerical value of the coefficients $(b_0, \ b_1, \ b_2, \ b_3, \ b_4, \ b_5, \ b_6)$ will be determined by applying multiple linear regression.

$$ PELM_{Nav} = b_0 + b_1 V_{Nav} + b_2 \text{TDW}_{Nav} + b_3 \text{LTCEX}_{Nav} + $$
$$ + b_4 \text{LITub}_{Nav} + b_5 \text{LITab}_{Nav} + b_6 \text{LTInt}_{Nav} \quad (2) $$

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

3. Case study

For the case study carried out in this paper, a database was used for 108 bulk carrier ships, which were repaired at the Constanta Shipyard, Romania. For the space saving of the work, only the limits (minimum and maximum) of variation of the values for the independent variables are indicated in table 1.
Table 1. The limits of variation of the values for the independent variables.

| Variable   | Value                        |
|------------|------------------------------|
| \( V_{Nav} \) | minimum – 3 (years)          |
|            | maximum – 41 (years)         |
| \( TDW_{Nav} \) | minimum – 20 500 (tons)     |
|            | maximum – 185 000 (tons)     |
| \( LTCEX_{Nav} \) | minimum – 284 (sqm)         |
|            | maximum – 13881 (sqm)        |
| \( LITub_{Nav} \) | minimum – 0 (lm)            |
|            | maximum – 784 (lm)           |
| \( LITab_{Nav} \) | minimum – 20 (kg)           |
|            | maximum – 73021 (kg)         |
| \( LTInt_{Nav} \) | minimum – 0 (sqm)           |
|            | maximum – 39 255(sqm)        |

The study was approached in two stages:
Stage 1: individual expression of the variation of the six independent variables (highlighted in equation (1) according to the dependent variable which is the period of performing the maintenance work of the ship (in number of days) in the dock and / or the quay.
Stage 2: expression of the period of performing the maintenance work of the ship (in number of days) in the dock and / or the quay, depending on two or more variables

The general goals pursued, in the two stages, were: determining the analytical expressions of the regression functions; expressing the numerical value of the interception and the regression coefficients \( b_0, b_1, b_2, b_3, b_4, b_5, b_6 \); calculation of the multiple coefficient of determination, \( R^2 \); calculation of the multiple correlation ratio, \( R \); highlighting the dispersion analysis (ANalysis Of Variance – ANOVA test).

For stage 1, the analytical expression of the regression function, for each independent variable, is:

\[
P_{ELM_{Nav}} = 12.81 + 0.33792 V_{Nav} \tag{3}
\]

\[
P_{ELM_{Nav}} = 23.07 - 5.7 \cdot 10^{-5} TDW_{Nav} \tag{4}
\]

\[
P_{ELM_{Nav}} = 23.038 - 3 \cdot 10^{-4} LTCEX_{Nav} \tag{5}
\]

\[
P_{ELM_{Nav}} = 19.028 - 8.3 \cdot 10^{-3} LITub_{Nav} \tag{6}
\]

\[
P_{ELM_{Nav}} = 20.902 - 6 \cdot 10^{-5} LITab_{Nav} \tag{7}
\]

\[
P_{ELM_{Nav}} = 18.796 - 7 \cdot 10^{-5} LTInt_{Nav} \tag{8}
\]

The results obtained in the second stage are summarized below.

For two independent variables, the regression function is:

\[
P_{ELM_{Nav}} = 19.68 + 0.34 V_{Nav_1} + 1.3 \cdot 10^{-6} TDW_{Nav_1} \tag{9}
\]

The value of the multiple determination coefficient is \( R^2 = 0.2327 \) and the multiple correlation coefficient is \( R = 0.4824 \).

For three independent variables, the regression function is:

\[
P_{ELM_{Nav}} = 19.36 + 0.25 V_{Nav_1} - 3.1 \cdot 10^{-5} TDW_{Nav_1} - 0.3809 LTCEX_{Nav_1} \tag{10}
\]
The value of the multiple determination coefficient is $R^2 = 0.241$ and the multiple correlation coefficient is $R = 0.4909$.

For four independent variables, the regression function is:

$$PELM_{Nav} = 22.51 + 0.2682V_{Nav} - 4.310^{-5}TDW_{Nav} - 0.6236LTCEX_{Nav} - 0.0058LITub_{Nav}$$

The value of the multiple determination coefficient is $R^2 = 0.2525$ and the multiple correlation coefficient is $R = 0.5025$.

For five independent variables, the regression function is:

$$PELM_{Nav} = 22.35 + 0.2650V_{Nav} - 4.910^{-5}TDW_{Nav} - 0.5856LTCEX_{Nav} - 0.0055LITub_{Nav} + 0.0231LITab_{Nav}$$

The value of the multiple determination coefficient is $R^2 = 0.2531$ and the multiple correlation coefficient is $R = 0.5031$.

For six independent variables, the regression function is:

$$PELM_{Nav} = 22.345 + 0.2693V_{Nav} - 4.810^{-5}TDW_{Nav} - 0.5433LTCEX_{Nav} - 0.0051LITub_{Nav} + 0.0217LITab_{Nav} - 2.6210^{-5}LTInt_{Nav}$$

The value of the multiple determination coefficient is $R^2 = 0.2536$ and the multiple correlation coefficient is $R = 0.5036$.

For six independent variables, the statistical analysis of regression is presented in table 2, table 3 and table 4.

**Table 2.** The limits of variation of the values for the independent variables.

| Regression coefficients | Standard error | T test | Probability |
|-------------------------|----------------|--------|-------------|
| Interception            | 22.34560195    | 7.267045533 | 3.07492252 | 0.002709  |
| $V_{Nav}$               | 0.269257156    | 0.116185967 | 2.31746711 | 0.022496  |
| $TDW_{Nav}$             | -4.84948E-05   | 4.58112E-05 | -1.0585792 | 0.292317  |
| $LTCEX_{Nav}$           | -0.00054332    | 0.000458855 | -1.1840789 | 0.239161  |
| $LITub_{Nav}$           | -0.005062572   | 0.004985715 | -1.0154154 | 0.312334  |
| $LITab_{Nav}$           | 2.17075E-05    | 8.74022E-05 | 0.24836321 | 0.804358  |
| $LTInt_{Nav}$           | -2.62562E-05   | 9.52124E-05 | -0.2757648 | 0.783292  |

**Table 3.** Statistics of regression.

|                      |                  |                  |                  |
|----------------------|------------------|------------------|------------------|
| $R$ – multiple correlation coefficient | 0.503599828 |                  |                  |
| $R^2$ – multiple determination coefficient | 0.253612787 |                  |                  |
| $R^2_{c}$ – corrected multiple determination coefficient | 0.209272952 |                  |                  |
| Standard error       | 7.01374244      |                  |                  |
| Number of ships entered in the database | 108            |                  |                  |
### Table 4. ANOVA test.

| Degrees of freedom | Variance (sum of squares) | Corrected dispersion (average of squares) | F statistic | Significance threshold for F statistic |
|--------------------|---------------------------|------------------------------------------|-------------|---------------------------------------|
| Regression line    | 6                         | 1688.215783                              | 281.369297  | 5.71975                               | 3.74507E-05                          |
| Residual factor    | 101                       | 4968.450884                              | 49.192583   |                                       |                                       |
| Total              | 107                       | 6656.666667                              |             |                                       |                                       |

The interpretation of the results is presented in Table 5, with the observations below.

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

Multiple coefficient of determination, $R^2$, which is the square of the multiple correlation coefficient, shows the proportion of the total variation of the dependent variable, which is explained by the independent variables. In economic practice, a multiple correlation is considered to be strong enough if the value of the coefficient of determination is greater than 0.7 (or 70%, in percentage terms).

### Table 5. Value for $R^2$ and $R$.

|                      | $R^2$ | $R$  |
|----------------------|-------|------|
| **Stage I**          |       |      |
| $f(V_{Nav})$         | 0.2327| 0.4824|
| $f(TDW_{Nav})$       | 0.0839| 0.2896|
| $f(LTCEX_{Nav})$     | 0.0181| 0.1345|
| $f(LITub_{Nav})$     | 0.0458| 0.2141|
| $f(LITab_{Nav})$     | 0.0170| 0.1305|
| $f(LITnt_{Nav})$     | 0.0004| 0.0200|
| **Stage II**         |       |      |
| $f(V_{Nav}, TDW_{Nav})$ | 0.2327| 0.4824|
| $f(V_{Nav}, TDW_{Nav}, LTCEX_{Nav})$ | 0.2410| 0.4909|
| $f(V_{Nav}, TDW_{Nav}, LTCEX_{Nav}, LITub_{Nav})$ | 0.2525| 0.5025|
| $f(V_{Nav}, TDW_{Nav}, LTCEX_{Nav}, LITab_{Nav}, LITnt_{Nav})$ | 0.2536| 0.5036|

Findings:
- the values of the multiple correlation coefficient, $R$, are small (between 0.4824 and 0.5036), which shows that the period of performing the maintenance work of the ship at the dock and at the quay in the shipyard (PELM$_{Nav}$) depends on many factors, each contributing in a certain proportion, quite small.
- the values of the multiple correlation coefficient, $R$, increase, as several independent variables are considered in the analysis, which reinforces, once again, the previous statement, namely that the period of performing the maintenance work of the ship at the dock and at the quay in the shipyard (PELM$_{Nav}$) depends on many factors to consider.
• when performing the analysis on a single independent variable, the age of the vessel, $V_{n_\text{av}}$, it intervenes with the greatest proportion, $R^2 = 0.2327$, in the total variation of the dependent variable, the other five having smaller proportions.
• the regression function from equation (13) is valid only for bulk-carrier vessels, for other types of vessels it is necessary to determine other regression functions.
• a regression function can also be developed for a database consisting of combined ship types.
• last but not least, the studies carried out so far lead to the finding that a database with a significantly larger number of ships is needed.

4. Conclusions
The period of carrying out the maintenance works of the ship at the dock and at the quay in a shipyard is important for the Owner / Technical Manager of the ship (both in his capacity as responsible for the development of the ship maintenance management process, and as a Beneficiary of the execution process of the maintenance works according to the requirements of the classification society) as well as for the shipyard in his capacity as Executor of the execution process of the maintenance works. Therefore, the period of performing the ship's maintenance work at the dock and quay in a shipyard is a key indicator of performance in achieving the objectives of the two management systems involved in the process.

According to the analyzes, it is found that in order to ensure the validity and useful regression functions resulting from the analysis being already dated from 108 bulk ship in bulk, the transport in force is always a fundamental factor for the fulfilment of the objectives.

The period of carrying out the maintenance works of the ship at the dock and at the quay in a shipyard for bulk-carrier type ships is in close correlation with the way of drawing up the Technical Specification, which must provide the necessary information (correct and complete) in relation to the volume and types of work to be carried out on the body and structures, machines, equipment, installations and systems. They must be supported by the necessary technical information from the plans approved by the classification society and from the technical documentation with reference to: technical description location / equipment, their number; the types of works necessary to be performed on location / equipment; the estimated quantitative volume (correct and complete) of the works necessary to be performed on the location / equipment.

The advantage of a Technical Specification of quality, consists in limiting the possibilities of appearing the orders of additional works during the execution of works for maintenance, upkeep and improvements on board the ship in the shipyard, so there are great chances to carry out the works, according to the initial estimate of the shipyard (by using the proposed regression function for bulk-carrier vessels), shipyard and ship costs are also possible to be maintained at the level of the initially estimated budgets.

Additional works during the execution of works for maintenance, upkeep and improvements on board the ship in the shipyard, cannot be excluded, whereas, in checking the condition of the hull and the structure of the ship in the dock, following the measurements of sheet metal thicknesses the appearance or evolution of the corrosion of the ship's bottom plates can be identified and also any deformations, ruptures or other damages of the hull structure can be identified. Also, regarding the machines, installations and equipment, following the verifications and measurements, non-conformities can be identified, these being necessary to be corrected by the execution of some works for the replacement of parts or repairs of certain subassemblies, which are additional to the initial Technical Specification.

In the case of unsatisfactory volume of information, a significant volume of orders for additional work may occur, with major implications for increasing the period of ship and quay maintenance work and the costs of both parties involved in the process.

For the shipyard, the additional works have a negative influence, due to the need to supplement the labor force to cover the additional volume of works ordered for the ongoing project and due to the
immobilization over the estimated term of the technical capacities, thus there is the major risk of being negatively affected and the development of the other projects undertaken in the respective period. For the Ship Owner / Technical Manager, the additional works have a negative influence, due to the additional costs necessary to cover the additional volume of works ordered and due to exceeding the period of maintenance of the ship at the dock and quay initially estimated, which may have a negative influence on the further development of the commercial obligations assumed by the ship.

5. References

[1] Castrillon Dussan, R, 2007 Shiprepair competition: drivers and opportunities, Dissertations, (Malmö, Sweden: World Maritime University)

[2] Coetzee, J L, 2004 Maintenance (Victoria, USA: Trafford Publishing)

[3] Cotaină, D., et.al., Study of existing Reliability Centred Maintenance (RCM) used in different industries (Spain: Universidad Politecnica de Madrid)

[4] Gulati, R, Smith, R, 2009, Maintenance and reliability best practices, (New York, USA: Industrial Press, Inc.)

[5] Lyngstol, T, 2002, Improvement of Ship Drydock Specifications: A Case Study, Master Thesis, (University of New Orleans and Norwegian University of Science & Technology)

[6] Mărăscu-Klein, V, Toma, V, 2007, Maintenance management, (Brasov, Romania: Transilvania University Pub. House)

[7] Pinjala, SK, Pintelon, L, Vereecke, A, 2006, An empirical investigation on the relationship between business and maintenance strategies, Int. Jour. of Production Economics, 104(1), p 214, Great Britain

[8] Arun, KD, Makaraksha, S, 2015 Modeling and analysis of ship repairing time Journal of Ship production and Design, SNAME Journal 31(1) p 1

[9] Manea E, Militaru C, Zăgan R, Chiţu M G, 2016, Improving Organizational Performance through the Application of Integrated Management Systems in Maintenance Activities in the Shipyards, Annals of Maritime University of Constanta, Romania, year XVI 24 p 57 p 221

[10] Manea E, Chiţu M G, 2013, Ships New Buildings, Repairs & Conversions Outlook 2009-2012. Trends Annals of Maritime University of Constanta, Romania, year XIV 19 p 57

[11] Manea E, Manea M G, 2018, The Risk Concept and the Impact on the Organizational Performance of Maritime Shiprepairs Shipyards Advanced Engineering Forum 2019 34 300–308 https://doi.org/10.4028/www.scientific.net/aef.34.300

[12] Manea E, Manea M G, 2019, The Influence of the Deadweight in the Projection of the Duration of the Maritime Ships Mentenancy Works Advanced Engineering Forum 2019 34 292–299 https://doi.org/10.4028/www.scientific.net/aef.34.292

[13] Manea E, Zăgan R, Manea M G, Militaru C (coordinator), 2018, Improving Shipyard Maintenance and Performance Vol. 1: Quality Management Applied to Improving Shipyard Maintenance and Performance (Constanta: Dobrogea Pub. House)

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