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Problems of ship repairing and maintenance activities in shipyards and mathematical methods to solve that

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Abstract. Mathematical statistics are applied in the field of engineering sciences where there are conditions of risk and uncertainty and where it is necessary to make some rigorously argued decisions. This paper purpouse is to illustrate, the opportunity to use probability theory in solving complex problems from the maritime vessels shipyard maintance and repairing activity, conditioned by uncertainty, risk and variability. The authors intended to demonstrate the fact that usinng the theory of probabilistic calculations could provide an efficient solution for the maintenance work of the drydocked ships in respect with requirement of the classification societies.

1. Introduction

Time, understood as the total period of maintenance work on board of a ship in the shipyards repair docks (dry or floating) and / or at the quai of a shipyard, is an essential component in managing maintenance work, influencing both costs and compliance with contractual requirements. The total period of maintenance work on board of a ship and the docking period are very difficult to quantify in order to have an efficient forecast, due to a significant number of random variables.

The researchers are interested in finding mathematical models, based on the use of probability theory and mathematical statistics, which could provide a solution to satisfy the need to predict efficiently the time required for carrying out maintenance work on ships in the dock and / or at quay in a shipyard, as part of the maintenance program imposed by the classification societies. The authors of this work, over time, have paid attention to this subject in various published works [1], [2], [3].

2. Theoretical considerations

Probability theory and mathematical statistics are applied in the field of engineering sciences where there are conditions of risk and uncertainty and where it is necessary to make some rigorously argued decisions. Probability theory studies random experiences, that is, those experiences that, repeated several times, take place each time differently, the result cannot being anticipated.

The main probability laws of discrete random variables, recommended in the literature, are: uniform discrete law; the binomial law with the particular case of Bernoulli law; the binomial law with negative exponent with the particular case of the geometric law; hypergeometric law; Poisson law (the law of rare events) [4], [5], [6] [7], [8].

The main probability laws of continuous random variables are: uniform continuous law (rectangular); normal law (Gauss-Laplace); the log-normal law; gamma law; law beta; Law χ^2 (Helmert-Pearson); student law (t) with the particular case of Cauchy law; Snedecor law; Fisher's law; Weibull law with the particular case of exponential law [4], [5], [7].

Researching economic phenomena and processes using modeling has developed explosively in recent decades. The model is, according to the definitions found in the specialized literature [25], a conventional image of the studied object / product / phenomenon / process. From the multitude of observed characteristics, the researcher retains only the essential ones and obtains a simplified image of the studied object / phenomenon.

Following some remarkable developments in the field of computer-aided computing, Von Neumann and Ulam proposed that, instead of using integer-differential equations (in order to obtain probabilistic solutions for the problems) to generate selections through random number experiments to obtain solutions which are not necessarily probabilistic in nature. They named this method "Monte Carlo" after casinos whose roulette can be considered as a tool for generating random numbers [9].

Currently, the simulation method "Monte Carlo" is increasingly applied for the analysis of stochastic problems or at risk conditions, when the same direction of action can have several consequences, the probabilities of which can be estimated. Probabilities play an important role in modeling the situations in which stochastic sizes occur. In simulation, knowledge about probabilities is required both in the construction phase of the simulation model and in the analysis phase of the simulation results. In many scientific fields three types of simulation models are used [10]: imitative models; analog models; symbolic models. Simulation models can also be classified as follows [11]: static models or dynamic models; deterministic models or stochastic models; discrete or continuous models.

In case a deterministic problem is associated with a random (probabilistic) model and, by generating random variables functionally linked to the solution and experiments on the model are performed and is provided information on the solution of the deterministic problem, the "Monte Carlo" simulation is used. The expression "Monte Carlo method" [9] is synonymous with the method of statistical experiments. The method is based on some conclusions derived from the limit theorems of probability theory. The method involves estimating the parameters of the distribution of a random variable based on its achievements. Thus, the main problem solved by the "Monte Carlo" method is to estimate the average value of a random variable based on an admissible error and a given probability.

3. Some examples

In the case of complex real systems - such as the maintenance process of the docked ships in the repair shipyards - the modeling is irreplaceable, presenting a series of advantages:

- the object / phenomenon under investigation can be represented without distortions generated by foreign phenomena or insignificant details;
- allows to carry out experiments where this would be impossible due to the difficulties of accessibility or due to the extremely high costs;
- offers the possibility of repeating the experiment until the essence of the phenomenon is known and conclusions can be obtained;
- allows to modify the characteristics of the real system and study under the new conditions;
- the study of model-based processes is cheaper, involves lower risks and considerably reduces the analysis time.

If during repeated measurements obtained results are very different from the vast majority of the results, it is assumed that there have been aberrant errors and it is necessary to analyze the opportunity of eliminating them during the statistical processing of the results. This operation is possible based on tests that require the choice of a probability depending on which may be make the decision to keep or eliminate them.

The tests to eliminate the data affected by aberrant errors are: Chauvenet test (3σ test); the Romanovski test; the Irwin test (the λ test); the Grubbs test; the Dean-Dixon test (Q test). The tests for checking the concordance between a theoretical distribution and an empirical distribution (determined experimentally) are: the test for checking normality (test χ^2); test for large number of values (Kolmogorov-Smirnov test); Massey-Junior test; Shapiro-Wilk test [12].

Table 1. Identification of aberrant errors

For the execution of the same maintenance work on a series of 19 ships, relatively similar in type and capacity of transport, in a shipyard there was a labor consumption, expressed in working hours, according to the table below. It is required to determine whether the missing value $x_d = 149$ hours it is erroneous to the value string and whether it should be eliminated from calculations.

The string is sorted in ascending order and the problem is solved using (one at the time) the tests for eliminating aberrant errors (EXCEL software was used to solve).

TEST IRWIN	TEST GRUBBS	TEST ROMANOVSKI
$\bar{x} = \frac{\sum_{i=1}^{19} x_i}{19} = 172{,}842$	$\bar{x} = \frac{\sum_{i=1}^{19} x_i}{19} = 172{,}842$	$\bar{x} = \frac{\sum_{i=1}^{19} x_i}{19} = 172{,}842$
$s = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - \bar{x}}{n-1}}$	$s = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}}{n-1}}$	$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-2}}$
$s = 177{,}75$	$s = 173{,}035$	$s = 8{,}645$
$\lambda_{calc} = \left\lvert\frac{x_d - x_a}{s}\right\rvert$	$G_{calc} = \frac{\lvert x_d - \bar{x}\rvert}{s}$	$R_{calc} = \frac{\lvert x_d - \bar{x}\rvert}{s \cdot \sqrt{\frac{n}{n-1}}},$
$\lambda_{149} = 0{,}084$	$G_{149} = 0{,}138$	$R_{149} = 2{,}684$
For a level of confidence of 95% $\lambda_{critic} = 1{,}03$	For a level of confidence of 95% $G_{critic} = 2{,}62$	For a level of confidence of 95% $R_{critic} = 2{,}75$
For a level of confidence of 98% $\lambda_{critic} = 1{,}28$	For a level of confidence of 98% $Gu_{critic} = 2{,}62$	For a level of confidence of 98% $R_{critic} = 2{,}93$
For a level of confidence of 99% $\lambda_{critic} = 1{,}81$	For a level of confidence of 99% $Gu_{critic} = 2{,}65$	For a level of confidence of 99% $R_{critic} = 3{,}05$
$\lambda_{149} < \lambda_{critic}$	$G_{149} < \lambda_{critic}$	$t_{149} < \lambda_{critic}$
149 it is NOT eliminated	149 it is NOT eliminated	149 it is NOT eliminated

The methods and techniques most commonly used in project management are Critical Path Analysis – CPM [13]. These focus the managers attention on the possible risks during the evolution of the projects which, in the case of carrying out a project of maintenance work on a ship in a shipyard, may arise for various reasons, such as:

- delay of the ship on arrival at the shipyard for the commencement of maintenance work due to commercial obligations, disturbance of maritime traffic due to certain restrictions on passage through straits, such as adverse weather conditions;
- the arrival of the ship in the shipyard without being properly prepared for the execution of the maintenance works, regarding the condition of obtaining the gas-free and hot work certificates in the places where it is necessary to perform maintenance works, the lack of spare parts and the specific materials needed to carry out the works;
- the necessity of extending the volume of maintenance work through additional orders compared to the initial Technical Specification, as a result of carrying out the inspections of the classification society for re-certification, so that by extending the volume of work it is necessary to allocate additional labor force to the shipyard;
- if the extension of the maintenance work required to be carried out at the ship by additional orders implies a delivery time greater than the initial agreed one, there may be disturbances in the shipyard program for the contracted ships to perform works in the dock and at quay.

Table 2. The network of a project and the scheduling of activities

When docking a tanker with a deadweight displacement of 159 089 tdw, having the year of construction 1995, maximum length 275 m, width 48 m, the list of maintenance work required to be performed in a shipyard includes:
Exterior body treatment works:

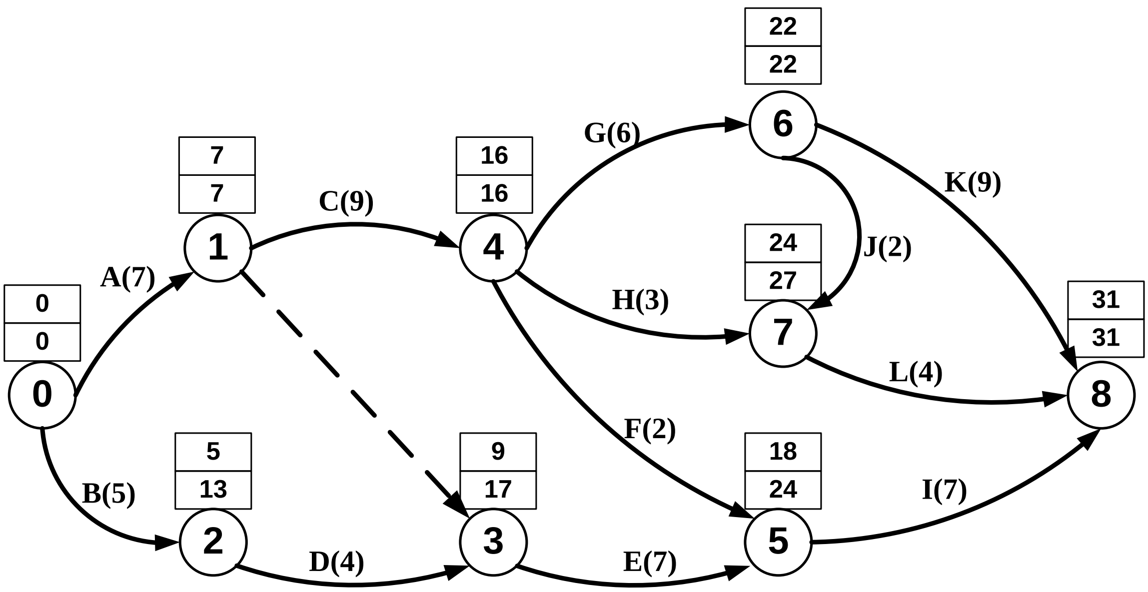
- flushing 24 000 m²
- Sandblasting SA1 and SA 2 4 000 m²

Cleaning and evacuation of existing sediments in the forepeak 70 m³
Table replacement work in the forepeak 50 000 kg
Blasting and painting treatment in the forepeak 3 000 m²
Propeller disassembly and axial line extraction.

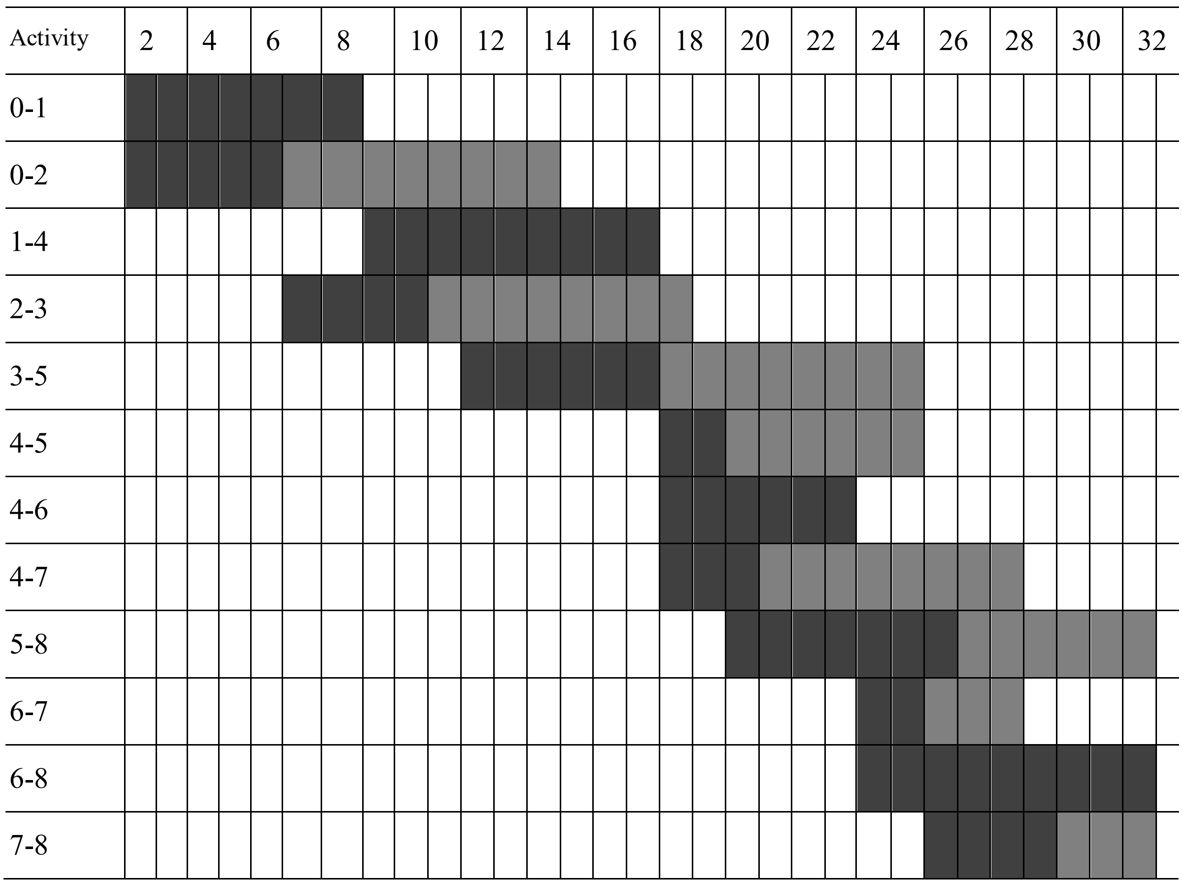
Activity	Directly preceding activity	Duration (in days)
A= sediment / sludge cleaning works in forepeak and evacuation	-	7
B= propeller and axial line work	-	5
C= replacement of damaged structures boards in the forepeak	A	9
D= washing the outer body of the vessel with high pressure water jet	B	4
E= sandblasting the outer body of the ship	A,D	7
F= internal structure sandblasting at the forepeak	C	2
G= blowing air and cleaning surfaces after sandblasting in the forepeak	C	6
H= low pressure water wash of forepeak structure	C	3
I = painting of anti-corrosive and anti-vegetative layers on the outside of the ship body	E,F	7
J= exhaust of the used grit of forepeak	G	2
K= paint anticorrosive layers in the forepeak	G	9
L = paint stripe-coat in forepeak	H,J	4

The minimum terms of the events (forward step)
$T_{E0} = 0; T_{E1} = max\{(0+7)\} = 7; T_{E2} = max\{(0+5)\} = 5;$
$T_{E3} = max\{(7+0),(5+4)\} = 9; T_{E4} = max\{(7+9)\} = 16;$
$T_{E5} = max\{(9+7),(16+2)\} = 18; T_{E6} = max\{(16+6)\} = 22;$
$T_{E7} = max\{(22+2),(16+3)\} = 24;$
$T_{E8} = max\{(18+7),(22+9),(24+4)\} = 31$
The maximum terms of the events (backward step)
$T_{L8} = 31 = T_{E8}; T_{L7} = min\{(31-4)\} = 27$
$T_{L6} = min\{(31-9),(27-2)\} = 22; T_{L5} = min\{(31-7)\} = 24$
$T_{L4} = min\{(24-2),(27-3),(22-6)\} = 16$
$T_{L3} = min\{(24-7)\} = 17; T_{L2} = min\{(17-4)\} = 13$
$T_{L1} = min\{(16-9),(17-0)\} = 7;$
$T_{L0} = min\{(7-7),(13-5)\} = 0 = T_{E0}$

Based on the list of activities in the table, the project network was drawn.



The schedule of the project activities is represented in the Gantt diagram



The „Monte Carlo" simulation can be used to analyze the flow of processes involved in the maintenance of a ship in a shipyard, as it represents a system characterized by the input and output variables that can interact and therefore the same direction of action can have several consequences

Table 3. Aplication of "Monte Carlo"method

A new set of welding devices has been introduced in the light fitting workshop of a shipyard which, depending on the type of operations, the thickness of the boards and the skill of the welders, allows different physical productions to be obtained. The productions obtained during 100 working hours are presented in the table below.

Amount of sheet replaced per day [kg]	Number of cases
120	2
200	5
220	11
280	15
320	20
410	15
450	12
490	13
520	5
590	2

The aim is to know the performances, in time, at the light fitting workshop.

The performances can be determined with the simulation method "Monte Carlo", in which, the performance evaluation operation is based on the observations made during the 100 working hours. The probability and the cumulative probability are calculated:

No.	Amount of sheet replaced per day [kg]	Probability	Cumulative probability
1	120	0,02	0,02
2	200	0,05	0,07
3	220	0,11	0,18
4	280	0,15	0,33
5	320	0,20	0,53
6	410	0,15	0,68
7	450	0,12	0,80
8	490	0,13	0,93
9	520	0,05	0,98
10	590	0,02	1,00

Extract 20 numbers from a table with random numbers in the range (0.1) and calculate the mean $\bar{X}$, the arithmetic mean deviation σ^2, the coefficient of variation C_V and the confidence interval.

No.	Random no.	Amount of sheet replaced per day [kg]	$(x_i - \bar{X})$	$(x_i - \bar{X})^2$
1	0,0317	200	-174,5	30450,25
2	0,9369	520	145,5	21170,25
3	0,3406	320	-54,5	2970,25
4	0,0200	120	-254,5	64770,25
5	0,9650	520	145,5	21170,25
6	0,6568	410	35,5	1160,25
7	0,7571	450	75,5	5700,25
8	0,6174	410	35,5	1260,25
9	0,1511	220	-154,5	23870,25
10	0,0306	200	-174,5	30450,25
11	0,2333	280	-94,5	8930,25
12	0,6603	410	35,5	1260,25
13	0,5447	410	35,5	1260,25
14	0,9134	490	115,5	13340,25
15	0,7861	450	75,5	5700,25
16	0,6969	450	75,5	5700,25
17	0,9277	490	115,5	13340,25
18	0,2388	280	-94,5	8930,25
19	0,5773	410	35,5	1260,25
20	0,6971	450	75,5	5700,25
		7490		268495,00

$$\bar{X} = \frac{7490}{20} = 374,5; \sigma^2 = \frac{268495}{20} = 13424,75; \sigma = 115,86; C_V = \frac{115,86}{374,5} = 0,309$$

The t distribution (Romanovski test) is used to verify the hypothesis regarding the average of the replacement table production. Performing the calculations, we obtain the quantity of sheet that is between 320 kg / hour and 428 kg / hour.

The number of experiments considered (20) makes this interval too large. Repeat calculations for other numbers of experiments, stabilize around 360 kg / hour, which represents the time performance of the light fiting workshop.

Repeat no.	400	2500	4500	6000	7500	9000
Medium value	359,425	359,332	361,693	359,297	360,817	360,960

4. Conclusions

Through the documentation made in this paper, but especially through the examples presented and considered to be illustrative, the authors concluded that a mathematical model based on the use of probability theory and mathematical statistics could provide a solution for satisfying the need to predict as much as possible effective period of time required for the execution of the maintenance works of the ships in the dock and / or at the dock in a shipyard, as part of the maintenance program imposed by the classification societies.

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