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Statistic mathematics – instrument for solving some problems in maintenance activities in the shipyards

E Manea[1], R Zăgan[2] and E Militaru[3]
[1]Constanta Shipyard SA, Greece Branch Office, Port Str., No.1, Constanta, RO
[2]Maritime University of Constanta, Electromechanics Faculty, Department of Engineering Science, Mircea cel Bătrân Str., No.104, Constanta, RO
[3]National Institute for Research and Development in Informatics, Mareşal Alexandru Averescu Ave., No 8-10, Bucharest, RO

E-mail: snc_cn@yahoo.com

Abstract. The organizational performance plays a fundamental role in the context of the increasing market competition, so that the chance of survival in this competition is considerably favorable for those organizations that very quickly discover and minimize their vulnerabilities and, moreover, implement management performance tools, which facilitates the detection, explanation and resolution of the various shortcomings of the management activities, the main objective being the competitiveness increasing. In the most general way, the study of maintenance involves the calculation of certain numerical indicators that aim to determine the reliability level: the probability of uninterrupted operation over a period of time; probability of success (functioning); the probability of failure (failure). 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. The probability theory studies random events, that is, those experiences that, repeated several times, occur each time differently, the result being not possible to be anticipated. The random variable, if a series of measurements is made, it is a notion that gives information about the value number of the measured size, as well as the frequency of occurrence of a numerical value in a row. This paper aims to illustrate, by means of justifying examples, 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. By the examples presented and considered to be illustrative, the authors of this paper consider that a mathematical model based on the theory of probabilistic calculations could provide a solution for satisfying the need to predict how efficiently the time required for carrying out the maintenance work of the ships in the drydock and / or on the berth in a shipyard, as part of the maintenance program required by the classification societies.

1. Introduction

The performance indicators [1] necessary to be analyzed with priority are based on the information of the bidding activities as price and time of the works carried out in the shipyards for the execution of the maintenance works performed on board the maritime vessels, as they are considered to be conducive for the approval and signing of a contract. For the bidding activity the performance indicators arising from: the number of offers submitted to clients and the number of accepted offers for contracting the execution of maintenance works; the number of offers accepted for contracting the execution of the maintenance works, at which the final invoice was under the project estimated budget on the Maintenance and Repairs works Quatation based on the Technical Works Specification Requirments prepared by the Owner / Technical Manager (customer profile - number of projects, geographical area; the volume and type of canceled works; docking, treatment and painting of surfaces, steel structures renewing, piping, mechanical, electrical) [1].

For the programming planning activity, the performance indicators arising from:

- the number of unsolicited offers due to the lack of docking capacities validity during the period required by customers (customer profile - number of vessels; geographical area; types of ships and their dimensions; period required for docking);
- the number of contracted ships that exceeded the agreed term of works completion (number of days delay; types of ships and their dimensions; volume and type of works that led to exceeding the term of completion; docking, treatment and painting of surfaces, steel structures renewing, piping, mechanical, electrical);
- the number of contracted ships that were delayed on arrival at the shipyard for the execution timely commencement of the maintenance works.

The bidding and scheduling-planning activities carried out in the shipyards for the execution of the maintenance 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 [2] such as: the level of the maritime transport market; weather conditions in certain periods in the geographical area where the shipyard is located; the type, capacity and age of the ship; differences in volume of the final works performed compared to the initial estimation due to the existing technical conditions found in the systems, installations and equipment of the ship after the beginning of the maintenance works.

In the most general way, the study of maintenance / repairs involves the calculation of certain numerical indicators that aim to determine the reliability level: the probability of uninterrupted operation over a period of time; probability of success (functioning); the probability of failure (failure); the average operating time between two defects; the average operating time until the first defect; average time for repair or replacement.

The safety in operation is a feature that changes over time. A low reliability and a high failure rate lead to a high level of operating expenses, which may, under certain conditions, exceed the initial costs incurred to make the respective equipment. On the contrary, a very high reliability and a very low failure rate lead to a very important reduction of the operating expenses, but also to an exaggerated increase of the price of the respective product [3].

The reliability theory is a discipline that studies the general laws that must be taken considered when designing, experimenting, manufacturing, receiving and exploiting products in order to obtain maximum efficiency following their exploitation. The reliability theory interferes with risk theory, which aims to reduce losses and risk of failure. The main notions of this theory are those of failure and no failure. Failure (breakdown) means the respective product parameters changing which leads to the loss of operating capacity. No failure means the ability of the product to maintain its operating capacity for a period of time determined by the operating conditions. The notion of failure is useful because it allows different numerical characteristics of the operating safety to be introduced.

The durability of a product is understood to be the ability to operate for a long time under the conditions of a proper technical service, which also includes the different categories of repairs. In general, the life of a product is different from the duration of no failure, being influenced by its maintenance defined to be the ability to prevent, detect and eliminate defects of the respective product.

2. Some examples

The probability theory studies random events, that is, those experiences that, repeated several times, occur each time differently, the result being not possible to be anticipated. The probability of an event A is equal to the ratio between the number of equally probable events favourable to event A and the total number of equally probable events (the definition applies only when elementary events are equally possible).

In another wording, the probability of an event is the ratio of the number of cases favourable to the event and the number of possible cases (according to this definition, the probability of an event belonging to an infinite field of events cannot be established). Some illustrative examples are shown in table 1, table 2, table 3 and table 4.

Table 1. Example 1 for probability theory applicability.

Task: It is necessary to perform maintenance work on the side ballast tanks of a bulk carrier. The ship has 6 ballast tanks on the port side and 6 ballast tanks on the starboard side. The works are executed as follows: simultaneously two tanks, one tank in each side. *Answer:* 1. The multitude of possible outcomes of starting work on a pair of tanks is given by the pairs of tanks that can be formed $E = \{11,12,\ldots,16,21,22,\ldots,26,31,\ldots,66\}$, $\lvert E\rvert = 6^2 = 36$, where $\lvert E\rvert$ note the number of elements of the mathematical set E. All possible outcomes are equiv. probable, so the probability of an event A, P(A), is equal to the number of elements in set A divided by the number of elements in E. 2. It is assumed that on one board the anodic protections will be replaced at the #1 tank and at the other tanks in the same board the bilge valves will be overhauled. It is noted with AV the event that at the first execution of the works begins with the replacement of the anodic protections at #1 tank and at the second execution of the works begins with the bilge valves overhauling. It is obtained $\mathrm{AV} = \{12,13,14,15,16\}$, so $P(AV) = \frac{5}{36}$. Similar, $\mathrm{P(AA)} = \frac{1}{36}$, $\mathrm{P(VA)} = \frac{5}{36}$, $\mathrm{P(VV)} = \frac{25}{36}$ 3. It is assumed that the numbering of the tanks are not considered but the works to be executed only are considered. In this case it is obtained $\mathrm{E} = \{\mathrm{AA}, \mathrm{AV}, \mathrm{VA}, \mathrm{VV}\}$ with the appropriate probabilities. It is observed that, in this case, the events *AA, AV, VA, VV,* are elementary and form a complete system of events.

The following rules should be considered:

Rule 1 - probability of difference: if $\mathrm{A}, \mathrm{B} \in \mathrm{K}$ and $\mathrm{A} \subset \mathrm{B}$, then

$$\mathrm{P(B-A) = P(B) - P(A)} \tag{1}$$

Rule 2 - probability of reunion (Poincaré's formula): if $\mathrm{A}, \mathrm{B} \in \mathrm{K}$, then

$$\mathrm{P(A \cup B) = P(A) + P(B) - P(A \cap B)} \tag{2}$$

Rule 3 - conditional probabilities: if $\mathrm{P(B)} \neq 0$, then the ratio $\frac{\mathrm{P(A \cap B)}}{\mathrm{P(B)}}$ (3)
is called the probability of A being conditioned by B and is noted $\mathrm{P_B(A)}$ or $\mathrm{P(A,B)}$.

Rule 4 - probability of meeting independent events: if $\mathrm{A_1, A_2, \ldots, A_n}$ there are independent, so

$$\mathrm{P}\left(\bigcup_{i=1}^{n} \mathrm{A_i}\right) = 1 - \prod_{i=1}^{n}\left(1 - \mathrm{P(A_i)}\right) \tag{4}$$

Rule 5 - Boole's inequality: if $\mathrm{A_1, A_2, \ldots, A_n}$ there are dependent events, then

$$\mathrm{P}\left(\bigcap_{i=1}^{n} \mathrm{A_i}\right) \geq \sum_{i=1}^{n} \mathrm{P(A_i)} - (n-1) = 1 - \sum_{i=1}^{n} \mathrm{P}(\overline{\mathrm{A}}_i) \tag{5}$$

Rule 6 - the total probability formula: if $\mathrm{A_1, A_2, \ldots, A_n}$ is a complete system of events and events $\mathrm{X} \in \mathrm{K}$, then

$$\mathrm{P(X)} = \sum_{i=1}^{n} \mathrm{P(A_i)} \cdot \mathrm{P_{A_i}(X)} \tag{6}$$

Rule 7 - Bayes formula: if $A_1, A_2, \ldots, A_n$ is a complete system of field events (Ω, K) and $X \in K$, then

$$P_X(A_i) = \frac{P(A_i) \cdot P_{A_i}(X)}{\sum_{i=1}^{n} P(A_i) \cdot P_{A_i}(X)}, i = \overline{1, n} \tag{7}$$

Table 2. Example 2 for probability theory applicability.

Task:
S_1, S_2, S_3 three workshops of a shipyard exceed the daily schedule for carrying out maintenance work performed on board a ship, with probabilities of 0.7; 0.8 respectively 0.6. To calculate the probabilities of the events, as follows:
A - at least one section to carry out before the deadline the maintenance works performed on board the ship.
B - all the workshops to carry out the maintenance work performed on the ship before the deadline.
Answer:
Let the event A_i is that the S_i workshop to carry out before the deadline the maintenance works executed on board the ship.
It is known that $A = A_1 \cup A_2 \cup A_3$, so

$$P(A) = P(A_1 \cup A_2 \cup A_3) = 1 - P(\overline{A}_1 \cap \overline{A}_2 \cap \overline{A}_3) = 1 - P(\overline{A}_1) \cdot P(\overline{A}_2) \cdot P(\overline{A}_3) = \\ = 1 - (1 - 0.7)(1 - 0.8)(1 - 0.6) = 1 - 0.3 \cdot 0.2 \cdot 0.4 = 0.976$$

$B = A_1 \cap A_2 \cap A_3$ and, taking into consideration the independence of events, it can be written:

$$P(B) = P(A_1 \cap A_2 \cap A_3) = P(\overline{A}_1) \cdot P(\overline{A}_2) \cdot P(\overline{A}_3) = 0{,}7 \cdot 0{,}8 \cdot 0{,}6 = 0{,}336$$

Table 3. Example 3 for probability theory applicability.

Task:
When performing the maintenance work of a 4-cylinder diesel engine in line, it is necessary to replace the segments at the 4 pistons using parts from the spare stock that consists of a total of 26 segments. It requires the probability that, by accident, extracting 5 times a segment and placing them in the order of extraction, the order of the segments on a piston (compression-I, scraper-I, lubrication, compression-II, scraper-II) is obtained.
Answer:
Note X the event looking for, so to obtain by successive extractions the order of assembly of the segments on a piston. It is also noted
A_1= the event that at the first extraction a compression segment I is obtained;
A_2 = the event that at the second extraction a scraper segment I is obtained;
A_3 = the event that at the third extraction a lubrication segment is obtained;
A_4 = the event as at the fourth extraction a compression segment II is obtained;
A_5 = the event that at the fifth extraction a scraper segment I is obtained.
Than, X event if $X = A_1 \cap A_2 \cap A_3 \cap A_4 \cap A_5$.
Result:

$$P(X) = \\ = P(A_1)P(A_2|A_1)P(A_3|A_1 \cap A_2)P(A_4|A_1 \cap A_2 \cap A_3)P(A_5|A_1 \cap A_2 \cap A_3 \cap A_4) = \\ = \frac{1}{26}\frac{1}{25}\frac{1}{24}\frac{1}{23}\frac{1}{22}$$

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Table 4. Example 4 for probability theory applicability.

Task:
A shipping company requests from three shipyards time and price quotations for carrying out the maintenance work on board a ship, so that the following situations can be met:
a) the company receives a quotation;
b) the company receives at most one quotation;
c) the company receives at least one quotation;
d) the company receives at least two quotations.
Answer:
a) the received quotation may be from the first shipyard requested, in case the other shipyards do not send quotations, or from the second shipyard, in which case the first and third do not send quotations or from the third shipyard, case in which the first two do not send quotations. It is found that the following event exists:

$$A = (U_1 \cap \overline{U}_2 \cap \overline{U}_3) \cup (\overline{U}_1 \cap U_2 \cap \overline{U}_3) \cup (\overline{U}_1 \cap \overline{U}_2 \cap U_3)$$

b) there are two variants: the shipping company does not receive any quotations or the shipping company receives a quotation. It is found that the following event exists:

$$B = (\overline{U}_1 \cap \overline{U}_2 \cap \overline{U}_3) \cup A$$

c) the event can be written as the meeting of three events: the shipping company receives an offer, two offers, three offers. So,

$$C = A \cup E \cup F$$

where,

$$E = (U_1 \cap U_2 \cap \overline{U}_3) \cup (\overline{U}_1 \cap U_2 \cap U_3) \cup (U_1 \cap \overline{U}_2 \cap U_3)$$

$$F = U_1 \cap U_2 \cap U_3$$

d) it is found that it exists $D = E \cup F$. Otherwise, D event is opposite to B event, so

$$D = \overline{B} = \overline{(\overline{U}_1 \cap \overline{U}_2 \cap \overline{U}_3) \cup A}$$

3. Applications for classical law of probability

The random variable, if a single measurement is made, is that size which, in an experiment, can take an unknown value a priori, and if a series of measurements is made, it is a notion that gives information about the value number of the measured size, as well as the frequency of occurrence of a numerical value in a row. If the numeric values of a data row belong to the integers or rationals set , then a discrete random variable is defined, and in the case of the values belonging to the real numbers set , a continuous random variable is defined. [4]

Discrete random variables refer to experiments or phenomena that are governed by statistical laws (when there is a certain degree of uncertainty about the occurrence of a result or its reappearance) and not by deterministic laws (when it is known with certainty what result will occur or not). In order for such experiments or phenomena to be known and therefore studied, the possible results of the experiment and the statistical law or the probabilities with which the results of the considered experiment are possible, are important and necessary.

Briefly, the main probability laws of the discrete random variables are the followings: the 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). The sources used for this paragraph are: [4-11]

The binomial law is known as the Bernoulli Law: an event has the p probability of achieving when the experience to which it is related occurs only once.

If α_n is the number of achievements of the event when the experience takes place n times, then:

$$\lim_{n\to\infty} P\left(\left|\frac{\alpha_n}{n} p\right| \geq \varepsilon\right) = 0, \forall\varepsilon > 0 \tag{8}$$

Some illustrative examples are shown in table 5 and table 6.

Table 5. Example for classical law of probability - discrete random variables.

Task:
When preparing a technical specification for maintenance work required to be performed on board a ship, those n independent works $A_1, A_2, \dots, A_n$ have the occurrence probabilities $P(A_k = p_k, k = \overline{1,n})$.
To calculate the average value and the dispersion of the number for independent works that are performed when the ship enters a shipyard for carrying out works according to the technical specification.
Answer:
It is noted with X the random variable that has as value the number of maintenance works that are carried out at the ship in the shipyard according to the technical specification. The probability of X taking the k $(k = 0,1,2,\dots,n)$ value is, according to Poisson's generalized binomial law, the coefficient x^k in the polynomial

$Q(x) = (p_1x + q_1)(p_2x + q_2) \dots (p_nx + q_n)$ where $q_i = 1 - p_i, i = 1,2,\dots,n$

If it is written unfolded, $Q(x) = a_0 + a_1x + a_2x^2 + \cdots + a_nx^n$, then the distribution table of variable X is

$$X: \begin{pmatrix} 0 & 1 & 2 & \dots & n \\ a_0 & a_1 & a_2 & \dots & a_n \end{pmatrix}$$

The sum of all the elements on the second line of the distribution table is 1 because

$$a_0 + a_1 + \cdots + a_n = Q(1) = (p_1 + q_1)(p_2 + q_2) \dots (p_n + q_n) = 1$$

The average value of variable X is $E(X) = \sum_{i=0}^{n} ka_k$.

By deriving the expression of the polynomial $Q(x)$ result:

$$\dot{Q}(x) = a_1 + 2a_2x + 3a_3x^2 + \cdots + na_nx^{n-1}$$

and is obtained

$$\dot{Q}(1) = a_1 + 2a_2 + 3a_3 + \cdots + na_n = \sum_{i=0}^{n} ka_k = M(X)$$

But then,

$$\dot{Q}(x) = p_1 \prod_{k=1} (p_kx + q_k) + p_2 \prod_{k=1} (p_kx + q_k) + \cdots + p_n \prod_{k=1} (p_kx + q_k)$$

And for $x = 1$ becomes $\dot{Q}(1) = p_1 + p_2 + \cdots + p_n$.

Thus, $E(X) = \sum_{k=1}^{n} p_k$.

For the dispersion calculation, it is initially calculated $E(X^2) = \sum_{k=0}^{n} k^2a_k$

Is obtained

$$x\dot{Q}(x) = a_1x + 2a_2x^2 + 3a_3x^3 + \cdots + na_nx^n$$

and by deriving result

$$\dot{Q}(x) + x\ddot{Q}(x) = a_1 + 2^2a_2x + 3^2a_3x^2 + \cdots + n^2a_nx^{n-1}$$

For $x = 1$, becomes $\dot{Q}(1)+x\ddot{Q}(1) = \sum_{k=1}^{n} k^2 a_k$, so

$$E(X^2) = \dot{Q}(1) + \ddot{Q}(1) = \sum_{k=1}^{n} p_k + \ddot{Q}(1)$$

Derive to calculate $\ddot{Q}(1)$ and obtain

$$\ddot{Q}(x) = p_1\left[p_2\prod_{j=1,2}(p_j x + q_j) + p_3\prod_{j=1,3}(p_j x + q_j) \dots + p_n\prod_{j=1,n}(p_j x + q_j)\right] +$$

$$+p_n\left[p_2\prod_{j=1,n}(p_j x + q_j) + p_2\prod_{j=2,n}(p_j x + q_j) \dots +p_{n-1}\prod_{j=1,n-1}(p_j x + q_j)\right]$$

For $x = 1$ becomes

$$\ddot{Q}(x) = p_1\sum_{k=1} p_k + p_2\sum_{k=2} p_k + \dots + p_n\sum_{k=n} p_k =$$

$$= p_1[E(X) - p_1] + p_2[E(X) - p_2] + \dots + p_n[E(X) - p_n] =$$

$$= E(X)(p_1 + p_2 + \dots + p_n) - (p_1^2 + p_2^2 + \dots + p_n^2) = [E(X)]^2 - \sum_{k=1}^{n} p_k^2$$

Is obtained

$$E(X^2) = \sum_{k=1}^{n} p_k + [E(X)]^2 - \sum_{k=1}^{n} p_k^2$$

$E(X)$ dispersion value is

$$Var(X) = E(X^2) - [E(X)]^2 = \sum_{k=1}^{n} p_k + [E(X)]^2 - \sum_{k=1}^{n} p_k^2 - [E(X)]^2 =$$

$$= \sum_{k=1}^{n} p_k - \sum_{k=1}^{n} p_k^2 = \sum_{k=1}^{n} p_k\,(1 - p_k) = \sum_{k=1}^{n} p_k q_k$$

The main probability laws of continuous random variables: 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. The sources used for this paragraph are: [4,6,7]

The log-normal law (X has normal logarithmic distribution) with considered parameters m and σ $(m, \sigma > 0)$ if its probability density (distribution) is the function

$$f(x; m, \sigma) = \begin{cases} \frac{1}{\sigma x\sqrt{2\pi}} e^{\frac{(lnx-m)^2}{2\sigma^2}}, x > 0 \\ 0, x \le 0 \end{cases} \quad (9)$$

Table 6. Example for classical law of probability - continuous random variables.

Task:
At the bottom inspection of a drydocked ship for repairs, measurements of the bottom steel plates thicknesses in 256 points are performed. What is the probability that the number of occurrences of bottom steel plates thicknesses below the allowed limit will be between 112 and 144?
Answer:
It is noted with X the random variable that has as value the number of occurrences of bottom steel plates thicknesses below the allowed limit when measurements are made on the bottom steel plates at the 256 points.
The variable X has the binomial distribution with the parameters $n = 256$ and $p = 1/2$ (the probability that a measurement made on the bottom steel plates will register a thickness below the permissible limit). It is necessary to calculate $P(112 < X < 144)$.
Because $E(X) = np = 128$ and $\sigma_x = \sqrt{npq} = 8$, then the relationship takes place

$$P(112 < X < 144) = P\left(-2 < \frac{X - 128}{8} < 2\right)$$

Use of the Moivre-Laplace theorem and approximation of the distribution $\frac{X-128}{8}$ with the standard normal distribution Y, will lead to

$$P\left(-2 < \frac{X - 128}{8} < 2\right) \cong P(-2 < Y < 2) = \phi(2) - \phi(-2) = 2\phi(2) \cong 0.95$$

4. Conclusions

The ship maintenance, repair and transformation sector is of strategic importance, and it is considered that the current shipyard network in the ship maintenance, repair and transformation sector in the European Union is well prepared and capable of responding to the growing development needs.

Despite the difficult economic climate, there are opportunities for this sector, which is explained by the widening of the world fleet and the increasing volume of old ships, as well as by the increasing need for transformation and modernization, due to the environment, energy and climate requirements in this area.

Booking the shiprepairsyard has become of crucial importance for shipowners, who often have to choose a compromise solution between:

- a financially attractive solution;
- the need to ensure the reliability of the intervention;
- the belief that the shipyard has the appropriate technology for the works to be executed;
- the need for the ship's retention time in the shiprepairsyard to be reduced.

By implementing integrated management systems, shipyards have outlined their policies so as to provide products and services at the level of customer expectations regarding the quality, safety and performance for the maintenance work performed in the drydocks and / or on the berths. [12]

It is concluded that time, understood as the total period of maintenance work on board a drydocked ship (in gravy or floating dock) and / or at the berth of a shipyard, is an essential component in the management of maintenance work, influencing both the costs and compliance of the agreed contractual terms.

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

By the examples presented and considered to be illustrative, the authors of this paper consider that a mathematical model based on the theory of probabilistic calculations could provide a solution for satisfying the need to predict how efficiently the time required for carrying out the maintenance work

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of the ships in the drydock and / or on the berth in a shipyard, as part of the maintenance program required by the classification societies

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