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Assessments regarding the planning and control of activities and resources for ship repair and maintenance works

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Abstract. The repair and maintenance operations carried out within a shipyard are correlated with the process of ensuring and managing the resources necessary to carry out the works included in the technical specification. Resource planning is a complex issue that can be addressed from several points of view. Initially, the planning of activities is done taking into account only the analysis of the time parameter and the dependencies between activities imposed by the technological process. The practice of the activities carried out in a shipyard has demonstrated that an analysis of the necessary resources according to the existing availability is also necessary. There are many unforeseen situations that can affect both the time of work and resources (material, financial, human) thus complicating the process of planning activities. This paper proposes a way to analyze the resource requirements of a repair project based on available resources, through Critical Path Method diagrams. This provides a comparative view of the daily required profile for a particular resource associated with the project in respect to the daily available profile of the shipyard.

1. Introduction

The time period during which a ship is accommodated in the shipyard for the maintenance works execution (in docked and/or berthed) can be easily included in the stochastic phenomena category influenced by a large number of deterministic or random, significant or insignificant acting factors.

A various specialized literature consulting concluded that the laws of probability and statistical tests could be used to solve chosen research topic for the thesis and by the realized documenting it was possible to develop contributions in solving issues concerning various activities involved in the complex process of the ships maintenance in the shiprepairs shipyards.

The information is getting increasingly important for organizational performance because it represents: the basic of the decisions - is important for the uncertainty reducing in decision making; a production factor – the information is important for the very high value products and services designing and delivering on the market (the enterprise high added value units or components are becoming increasingly equipped with means of access and processing information, automated flow being productive links); simultaneity factor - harmonizing actions component units of the organization to functions and its overall objectives fulfillment under the best conditions . The overall performance of an organization is conditioned by the weakest link, and the intensity of connections and relationships between units that compose the organization.

A data set representing the statistical characteristics values of a specified statistical community are called statistical data. There are three ways of obtaining these data: observation, experimentation and simulation. The classification methods in terms of accuracy highlights the following categories: accurate, approximate and heuristic.

Identification of the number of variables with significant influence and their inter-relationship as a result of the estimates made in the bidding and programming-planning activities carried out in the shipyards for the execution of the maintenance works of the maritime ships, has a special importance for the evaluation of the total period of time and of 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 [1], [4].

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 [15] [16] [17] [18] [19] [20] [21] [22].

The bidding and scheduling-planning activities carried out in the shipyards for the execution of maritime ship maintenance works are the result of some estimates operating with fixed data conditioned by variables belonging to a wide range of conditions and limitations such as [8], [12]: the level of the maritime transport market; weather conditions in certain periods in the geographical area where the shipyard is located; type, capacity and age of the ship; differences in the volume of the final works performed compared to the initial estimate due to the existing technical conditions found on the ship's systems, installations and equipment after the start of the execution of the maintenance works.

For the planning-programming activity, the performance indicators emerge from:

- the number of requests for unfulfilled offers due to the lack of validity of the docking capacities during the period requested by the clients: customer profile (number of ships); geographical area; types of ships (oil tanks, bulk carriers, container ships) and their dimensions; the period required for docking;
- the number of contracted vessels that have exceeded the agreed completion deadline: the number of delay days; types of ships (oil tanks, bulk carriers, container ships) and their dimensions; the volume and type of works that led to exceeding the completion deadline; dock works, treatment and painting of sheet metal surfaces, structural sheet metal replacements, piping, mechanics, electrical;
- the number of contracted ships that were delayed on arrival at the shipyard for the timely execution of maintenance works.

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

Repair and maintenance operations at a shipyard are related to 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 [2], [7], [9], [29]:

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 of 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.

2. Theoretical aspects

Critical Path Analysis methods [10], [11], [14] focuses managers' attention on possible risks and, in the case of a project for the execution of maintenance work on a ship in a shipyard, these may be: the delay of the ship on arrival at the shipyard for the start of maintenance works due to trade obligations, maritime traffic disruptions due to certain restrictions on crossing the straits, such as unfavorable weather conditions; the arrival of the ship at the shipyard without being properly prepared for the execution of maintenance works, regarding the condition of obtaining gas-free and hot work certificates in the locations where it is necessary to perform maintenance works, lack of spare parts and specific materials needed to carry out the works; the need to extend the volume of maintenance works through additional orders compared to the initial technical specification as a result of the classification society's inspections for recertification, so that by expanding the volume of works it is necessary to allocate additional labor by the shipyard;.

If the extension of the volume of maintenance work required to be performed on the ship by additional orders implies a longer delivery time than initially agreed, disruptions may occur in the shipyard's schedule for contracted ships to perform dock and quay work.

The project involves the completion of interconnected activities, which consume time and resources. The technological dependencies between activities are given by certain technological, financial, material and / or personnel constraints. Each activity corresponds to a start event and an end event. Activities that cannot be started until after an event will be preceded by activities that must be completed in that event.

The graphical representation of the set of activities of a project, as well as the dependencies between them, is called network or graph.

Terminology: each point (node) of the graph represents an event of the project, in terms of the start or end of one or more activities; each oriented arc that originates in one event (start) and destination in another event (end), represents an activity of the project; the start event of an activity (previous event) is noted generically, "i", and the final event of an activity is noted generically"j", the generic reference of an activity being made with the help of the indices of the two nodes between which is included the arc corresponding to the activity "a_{ij}". These networks are often called"diagrams_{ij}".

The theoretical structure of the method involves the following steps [27], [28]:

- the structural analysis of the project is carried out and, on the basis of it, a list of his activities is drawn up with the related time durations and the dependencies between them, imposed by the technological process;
- an activity cannot be started until all the activities whose final event corresponds to the start event of the one to be started have been completed;
- the graphs drawn;
- the order of representation of the activities in the graph must strictly respect the order and the dependencies imposed by the technological process;
- the nodes (events) of the graph are numbered, and above the arches (activities) is written the name of the activities and / or their duration;
- the event corresponding to the beginning of the first activity (activities) in the graph is called the initial event of the project, and the event corresponding to the completion of the last activity (activities) in the graph is called the final event of the project.

The following restrictions must also be considered:

- a project can have only one initial event and one final event;
- network loops are not allowed;
- "O" and "star" type connections are not supported.

The analytical structure of the method assumes that each event (node) is associated with two terms:

- T_E - earliest time (first – the earliest time that event may occur): $T_{E_i} = max\{L(D_{0,j})\}$, where $D_{0,j}$ represents one of the possible routes from event 0 to event i, $L(D_{0,j})$ represents the length of the route $D_{0,j}$;
- T_L - latest time (last – the latest time when that event may occur): $T_{L_i} = T_{E_n} - max\{L(D_{i,n})\} = \min\{T_{E_n} - L(D_{i,n})\}$, where T_{E_n} represents the minimum term of the final event of the project, $D_{i,n}$ represents one of the possible routes from event i to final event n of the project.

The algorithm of the method is presented below [24], [30].

In the first step, also called the forward step, the minimum event terms are calculated (dfrom the initial event 0, to the final event$n$); the resulting values are entered in the top box next to each network node.

In the second step, also called the backward step, the maximum terms of the events are calculated (from the final moment n, to the initial event i); the resulting values are entered in the lower box next to each node of the network.

Events whose minimum term is equal to the maximum term, $T_{E_i} = T_{L_i}$, are called critical events. These events cannot be delayed because they do not have time reserve.

Events whose minimum term differs from the maximum term, $T_{E_i} \neq T_{L_i}$, are called non-critical, they can be postponed with a maximum delay equal to the reservation of the event, $R_i = T_{L_i} - T_{E_i}$.

The route of the activities starting from the event 0 and go through the critical events in their numerical order, up to the event n, represents the critical path of the project (the path with the maximum duration).

3. Examples for ship repair work carried out on shipyards

Calculation of terms and time reserves of activities (see figure 1).

Theoretically, each activity a_{ij}, having a time duration d_{ij}, it is associated with four terms:

- the minimum start time, $T_S^{min}(i,j) = T_{Ei}$, where T_{Ei} it is the earliest moment when the event i can take place ;
- the minimum completion deadline, $T_f^{min}(i,j) = T_S^{min}(i,j) + d_{ij}$;
- maximum deadline, $T_f^{max}(i,j) = T_{Lj}$, where T_{Lj} it is the latest moment when the event j can take place;
- maximum start time, $T_S^{max}(i,j) = T_f^{max}(i,j) - d_{ij}$

If an activity is started, respecting the minimum start time $T_S^{min}(i,j)$, it evolves according to the minor program and if it is started respecting the maximum start term $T_S^{max}(i,j)$, it evolves according to the majoring program.

Also to each activity a_{ij}, having a time duration d_{ij}, four time reserves are associated with it:

- total reserve, $R_T(i,j) = T_{Lj} - (T_{Ei} + d_{ij})$ or $R_T(i,j) = T_f^{max}(ij) - T_f^{min}(ij)$
- free reserve $R_L(i,j) = R_T(i,j) - (T_{Lj} - T_{Ej})$ or $R_L = T_{Ej} - (T_{Ei} + d_{ij})$
- intermediate reserve $R_i(i,j) = T_{Lj} - (T_{Li} + d_{ij})$
- safe reserve $R_S(i,j) = \max\{T_{Ej} - (T_{Li} + d_{ij}), 0\}$

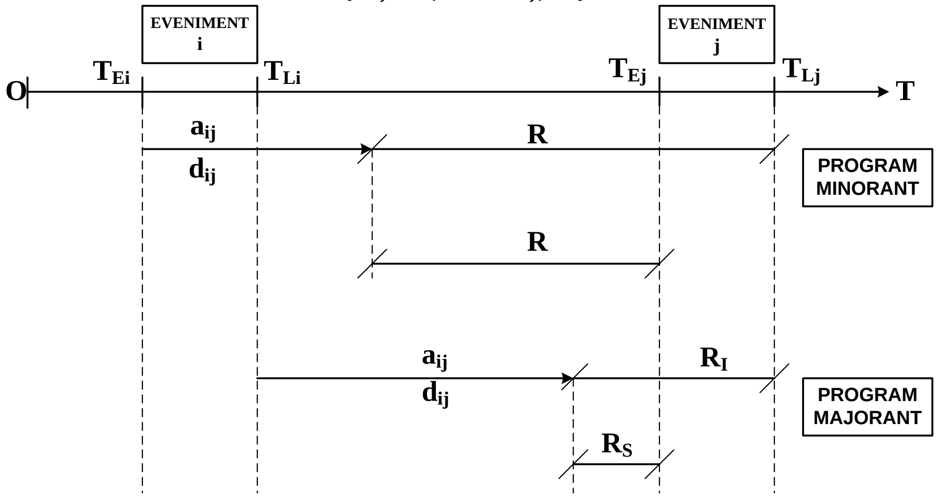

Fig.1. Time reserve
Source: [23]

Example no. 1:

When docking an oil tank with a deadweight displacement of 159 089 tdw, having a maximum length of 275 meters and the width of 48 meters, the list of maintenance works necessary to be executed in a shipyard includes:

Exterior hull treatment works: flushing 24 000 m²; sandblasting 4 000 m²

Sediment cleaning and evacuation works in forepeak 70 m³

Sheet metal replacement works in forepeak 50 000 kilos

Treatment works in forepeak sandblasting and painting 3 000 m².

Propeller disassembly work and axial line extraction.

Table 1. List of activities

Activity	Directly previous activity	Time (in days)
A= sediment / sludge cleaning works in forepeak and evacuation	-	7
B= works on the axial line and propeller	-	5
C= replaced damaged sheet metal structures in forepeak	A	9
D= washed the outer hull of the vessel with high pressure water jet (HPWJ)	B	4
E= sandblasting the outer hull of the ship	A,D	7
F= internal structure sandblasting at forepeak	C	2
G= blowing air and cleaning surfaces after sandblasting in forepeak	C	6
H= low pressure water jet washing forepeak structure	C	3
I = painting anticorrosive and antifouling layers on the outside	E,F	7
J= exhaust used grit from forpeak	G	2
K= painting anticorrosive layers in forepeak	G	9
L = stripe-coat painting in forepeak	H,J	4

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

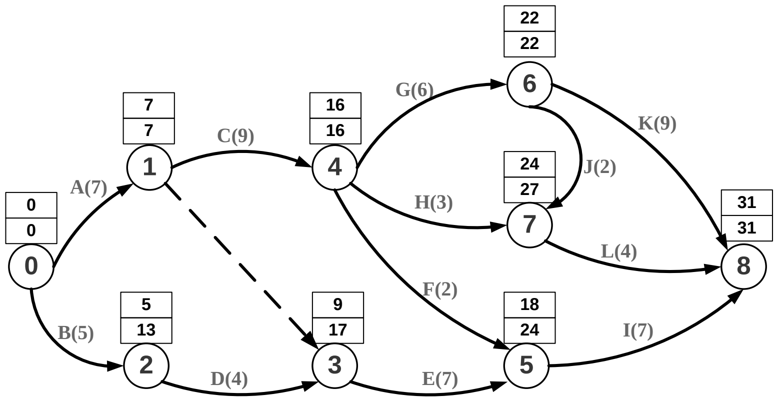

Fig.2. Project graph

Minimum event deadlines (forward step)

$T_{E0} = 0; T_{E1} = max\{(0+7)\} = 7; T_{E2} = max\{(0+5)\} = 5;$

$T_{E3} = max\{(7+0),(5+4)\} = 9; T_{E4} = max\{(7+9)\} = 16;$

$T_{E5} = max\{(9+7),(16+2)\} = 18; T_{E6} = max\{(16+6)\} = 22;$

$T_{E7} = max\{(22+2),(16+3)\} = 24;$

$T_{E8} = max\{(18+7),(22+9),(24+4)\ \} = 31$

Maximum event deadlines (backward step)

$T_{L8} = 31 = T_{E8}; T_{L7} = min\{(31-4)\} = 27$

$T_{L6} = min\{(31-9),(27-2)\} = 22; T_{L5} = min\{(31-7)\} = 24$

$T_{L4} = min\{(24-2),(27-3),(22-6)\} = 16$

$T_{L3} = min\{(24-7)\} = 17; T_{L2} = min\{(17-4)\} = 13$

$T_{L1} = min\{(16-9),(17-0)\} = 7;$

$T_{L0} = min\{(7-7),(13-5)\} = 0 = T_{E0}$

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

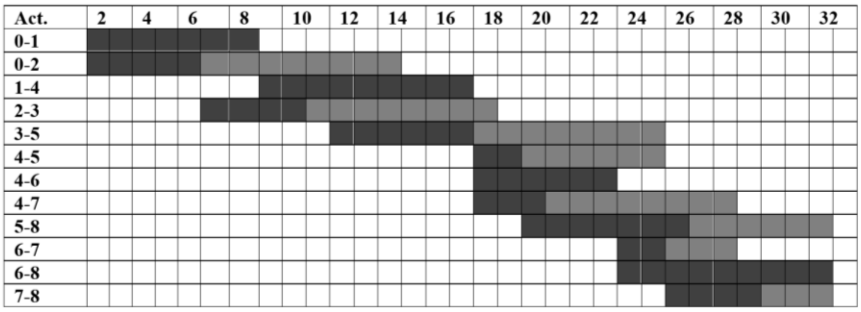

Fig.3. Gantt Diagram

Total reserve and free reserve [5] are the reserves associated with the activity that evolves according to the minor program and the intermediate reserve and the safe reserve are the reserves associated with the activity that evolves according to the majoring program.

The total reserve represents the time interval by which an activity can be delayed a_{ij}, started according to the minor program, so that the total duration of the project is not exceeded. The free reserve represents the maximum time interval by which an activity can be delayed a_{ij} started according to the minor program, so that the total duration of the project is not exceeded nor should the time reserves of successive activities be exceede (event time reserve j not to be exceeded).

The intermediate reserve represents the maximum time interval by which an activity can be delayed a_{ij}, started according to the majoring program, so that the total duration of the project is not exceeded nor should the time reserves of predecessor activities be canceled.

The safe reserve is the maximum amount of time an activity can be delayed a_{ij}, started according to the majoring program, so that the total duration of the project is not nor should the time reserves of predecessor and / or successor activities be affected.

If for an activity a_{ij}, $R_T = 0 \Rightarrow R_L = R_i = R_S = 0$, then the activity is critical, and if $R_T \neq 0$, then the activity is uncritical.

Resource planning [6], [13] is a complex issue that can be addressed from several points of view. Initially, the planning of activities is done taking into account only the analysis of the time parameter and the dependencies between activities imposed by the technological process. In order for the activities to be carried out according to the planner, human, equipment, financial or other resources are needed (specially arranged production spaces, etc.).

The need for resources for a program is not always similar to their availability within the company or the team. Usually, the availability is smaller, which requires a very careful allocation and scheduling of resources. Also, according to the initial planner, the daily requirement can fluctuate from one period to another or even from one day to the next, which can appear totally inefficient situations in terms of resource consumption. In this case, a leveling of the resources allocated for the elimination of unwanted variants is required, so that their use is optimal and efficient [25].

One of the classic methods of analyzing the resources needed for a project depending on availability is through diagrams, which provides a comparative view of the daily required profile for a particular resource associated with the project against the daily available profile of the company.

Example no. 2:

To a tanker of finished petroleum and chemicals products having a displacement of 40 000 tdw, analysis of the resources necessary for maintenance works required to be executed at a freight electro-pump with a flow rate Q = 3 000 m³/h positioned in the pump chamber and actuated by means of a cardan shaft by an electric motor with a power of 350 kw positioned in the ship's engine compartment, led, using the availability diagram, to the follow table and graph.

Table 2. List of activities

Activity	Directly previous activity
A = decoupling the pump electric motor by removing the drive shaft and sealed passage	-
B= disassembly of the pump housing	-
C = checking the rotor and stator windings of the electric motor with the power of 350 kw	A
D = disassembly of the pump shaft	B
E= rectification of the pump rotor	B
F = bearing replacement (electric motor, sealed passage and pump)	C,D
G = performing the pump-airtight-electromotive passage centering	E

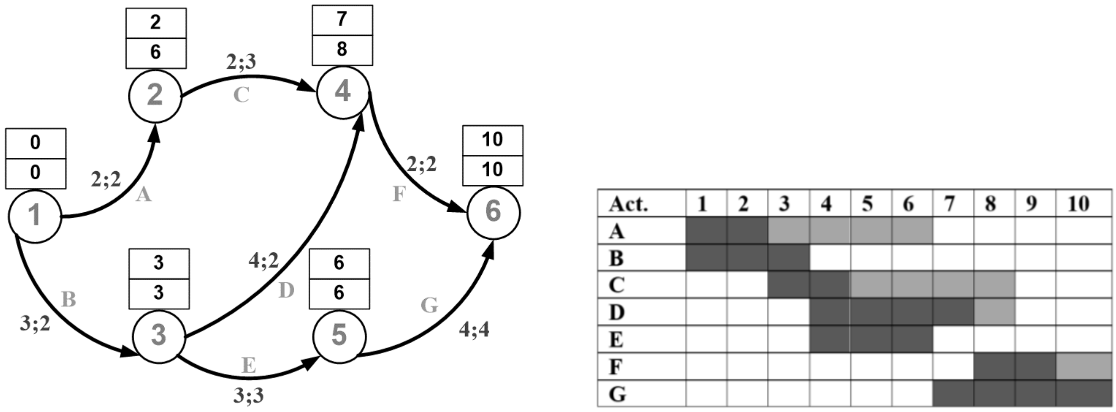

Fig.4. Project graph and Gantt diagram

The daily requirement of technicians for each activity is represented numerically, in tabular form and the cumulative daily needs of the project, the representation being calendaristic one.

Act.	1	2	3	4	5	6	7	8	9	10
A	2	2	--	--	--	--				
B	2	2	2							
C			3	3	--	--	--	--		
D				2	2	2	2	--		
E				3	3	3				
F								2	2	--
G							4	4	4	4
cumulat	4	4	5	8	5	5	6	6	6	4

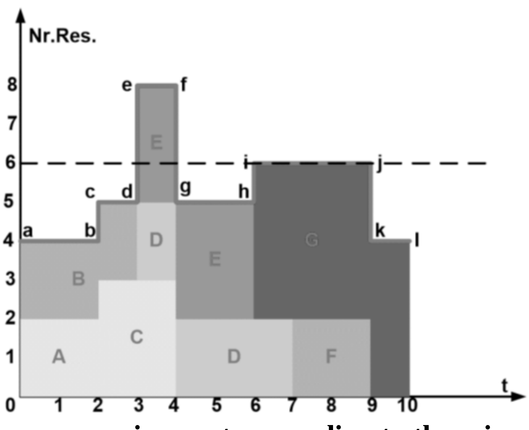

Fig.5. Daily requirement and profile of resource requirements according to the minor program

Contour a-b-c-d-e-f-g-h-i-j-k-l represents the profile of the necessary technicians, starting from the initial event to the final event. Considering that the availability of this type of resource is 6 (dotted line), it is necessary to level the allocation of the resource, if allowed, or to reschedule the activities.

Resource leveling seeks a solution for reprogramming non-critical activities within time reserves, so that the total duration of the project is not affected (the critical path remains the same), and the variations of resources to be reduced until obtaining an optimal profile.

Following the analysis of possible leveling solutions, it was decided to delay the activities D = disassembly of the pump shaft and F = bearing replacement (electric motor, sealed passage and pump), one day each, the result being illustrated in the in the following table and diagram.

Act.	1	2	3	4	5	6	7	8	9	10
A	2	2	---	---	---	---				
B	2	2	2							
C			3	3	---	---	---	---		
D					2	2	2	2		
E				3	3	3				
F									2	2
G							4	4	4	4
cumulat	4	4	5	6	5	5	6	6	6	6

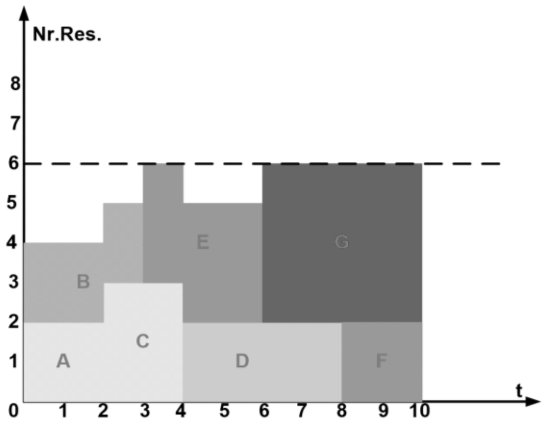

Fig.6. Daily requirement and level profile of resource requirements

4. Conclusions

Period of maintenance work on board a ship in the dock or at 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 in a satisfactory technical condition respecting the norms and norms in force [3].

Time, understood as the total period of maintenance work on board a ship in the repair dock (dry or floating) and / or at the dock of a shipyard, it is an essential component in the management of maintenance works, influencing both the costs and the observance of the contractual terms. Total period of maintenance on board a ship and the docking period are very difficult to quantify for efficient forecasting, due to a significant number of random variables.

By implementing integrated management systems, shipyards have outlined their policies according to the essential concern of ensuring that the products and services offered are delivered on time and are in accordance with international quality requirements and standards, the main objective being to increase competitiveness, including by reducing the retention time of ships in the dock and / or at the quay in order to carry out maintenance and repair work at the deadlines and at the quality level provided by the classification societies.

According to the requirements of the shipping companies, in order to maintain the competitiveness in conditions of economic efficiency, shipyard specialised in maintenance works, analyze their performance indicators with reference to: the percentage of contracting to the number of sent offers; percentage reduction in manufacturing / ship costs; duration of the dock cycle by ship types; the number of days of delay in the delivery of ships; the percentage of repetition of technical inspections for defects / ship.

Shipowners will always try to reduce the period of maintenance of the ship in the dock and / or at the quay, with the obvious aim of reducing the period in which they do not benefit from income from the operation of the ship. In turn, the shipyards will try to reduce the period of maintenance of the ship in the dock and / or at the quay, with the obvious purpose of maximizing revenue by contracting as many ships as possible.

The shipyards have become fairly quickly aware that customer satisfaction is of great importance to the international market development and success, requiring the strategies reconfiguration, the structures reorganization and the process improvement. Otherwise, if today dominant shipyards do not adapt will become non-performing and the weakest will finally disappear. Anticipating future challenges, the shipyards are concerned in profound changes making, on the integration for the excellence achieving focusing, which is a great potential area in all the aspects (quality, economic, financial, etc.)v

Since the SR EN ISO 9001: 2015 experienced a substantial change from the latest 2008 edition, by considering the risk concept, such as is possible, an approach for the future research targeting the shipyard organizational performance improving by applying a measures plan developed on the basis of the identifying and risk assessment that may adversely affect the achievements of the shipyard.

Would be possible the impact and probability assessing in the form of a inherent risk map representing the risk analysis not at the individual level only (eg critical risk / high / medium / low), but also about cumulative risks (for example: the concentration of certain risks that could pose a risk of total exposure greater than the sum of individual exposures, such as damage to reputation).

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