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Editorial Note

Cartagena de Indias, January 18th 2017.

In the year 2016, occurred one of the historical events for our Corporation, the signing of the first contract for the sale of a Logistic Support and Cabotage Unit (BAL-C) for the Honduran Naval Force. This is one of the most important sales of defense technology at the international level carried out by Cotecmar which involves a process of transfer of knowledge and technology to support the development of scientific and technological capabilities of the Honduran Naval Force. On the other hand, in the same year, Our Corporation received the "Accenture Innovation Prize", where Cotecmar presented itself in the category of Innovation in Products and Consumption Services with the same product, the Logistic Support and Cabotage Unit (BAL-C), becoming a technological and innovation reference product of interest to all the countries of the region.

The innovation developed for the ship ARC "Gulf of Tribugá" has been valued at the national level as a solution to the operational and civilian support for the needs of the most vulnerable coastal populations as well as remote and hard-to-reach military units. Likewise, its added value is characterized by being a multipurpose vessel that allows logistical support, evacuation to emergencies and humanitarian attention due to the use dual-use technology unique in Colombia.

We opened our edition with a work related to productivity in shipyards, we continued with the analysis and application of standards in the tests of the ship, then papers related to hydrodynamic calculations of propellers, the design of a system for reception of ballast water, and ending with the design of a rational model for decision-making for the selection of technologies in the defense sector.

Today, at the gates of the Fifth International Ship Design and Naval Engineering Congress, to be held from March 15 to 17, 2017 in Cartagena de Indias, where we expect the congregation of the national and international scientific community to share and discuss new knowledge in themes like the Design of Warships, Technological solutions for the fluvial industry and The proposals of strategies and initiatives for the sectorial development in the shipyard industry, we want to reiterate to our readers and authors our thanks for be linked and to support the development of this event where we count on their valuable participation.

Captain (Ret) CARLOS EDUARDO GIL DE LOS RÍOS
Ship Science and Technology Journal Editor

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Nota Editorial

Cartagena de Indias, 18 de Enero de 2017.

Finalizando el año 2016 se dio uno de los hechos históricos para la Corporación, la firma del primer contrato de venta de una unidad tipo Buque de Apoyo Logístico y Cabotaje (BAL-C) para la Fuerza Naval de Honduras, es una de las ventas de tecnología en defensa a nivel internacional más importantes realizada por Cotecmar que conlleva un proceso de transferencia de conocimiento y tecnología para apoyar al desarrollo de capacidades científico-tecnológicas de la Fuerza Naval de Honduras. Por otro lado, este mismo año se recibió el premio “Premio Accenture a la Innovación” donde Cotecmar se presentó en la categoría de Innovación en Productos y Servicios de Consumo con el mismo producto, el Buque de Apoyo Logístico y Cabotaje BAL–C, convirtiéndose entonces en un producto referente tecnológico y de innovación de interés para todos los países de la región.

La innovación del buque ARC "Golfo de Tribugá" ha sido valorada a nivel nacional como una solución a las necesidades operacionales y de apoyo civil para las poblaciones ribereñas más vulnerables así como para unidades militares apartadas y de difícil acceso. Igualmente, su valor agregado se caracteriza por ser una embarcación multipropósito que permite el apoyo logístico, la evacuación ante emergencias y atención humanitaria y por utilizar tecnología de uso dual única en Colombia.

Abrimos nuestra edición con un trabajo relacionado con productividad en astilleros, seguimos con el análisis y la aplicación de estándares en las pruebas del buque, luego trabajos relacionados con cálculos hidrodinámicos de hélices, el diseño de un sistema para recepción de aguas de lastre, terminando con el diseño de un modelo racional para toma de decisiones para la selección de tecnologías en el sector defensa.

Hoy a puertas del quinto Congreso Internacional de Diseño e Ingeniería Naval, a realizarse del 15 al 17 de Marzo de 2017 en Cartagena de Indias, se espera la congregación de la comunidad científica nacional e internacional para compartir y discutir el nuevo conocimiento en las temáticas de Diseño de Buques de Guerra, Soluciones tecnológicas para la industria fluvial y la propuestas de estrategias e iniciativas para el desarrollo sectorial en la industria astillera, queremos reiterar a nuestros lectores y autores las gracias por vincularse y apoyar el desarrollo de este evento donde contamos con su valiosa participación.

Capitán de Navío (RA) CARLOS EDUARDO GIL DE LOS RÍOS
Editor revista Ciencia y Tecnología de Buques

New implementation of Work Sampling Analysis for validating the Present Idle Time Indicator of Maintenance and Ship Repairing Business Line of Cotecmar

Nueva Implementación del Muestreo de Trabajo para Validación del Actual Indicador de Tiempo Ocioso Asociado a la Línea de Negocio de Reparación y Mantenimiento de Buques en Cotecmar

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Henry Murcia [2]
Raúl Fuciños [3]
Karen Domínguez [4]

Abstract

This article is focused on the implementation of the Work Sampling technique at the Science and Technology Corporation for the development of the Naval, Maritime and Riverine Industry – COTECMAR, more specifically in the Production Department of the Maintenance and Ship Repair Management located in Mamonal facilities; in order to know the percentage of idle times in performed productive processes and to identify the main triggers, through the estimation of the proportion of time played in specifics activities in a certain period of time, using instantaneous observations of work areas and employing probability sampling to generalize the findings.

Key words: Work Sampling, Probability Sampling, Idle Times.

Resumen

El presente artículo está orientado a la implementación de la técnica del muestreo de trabajo en la Corporación de Ciencia y Tecnología para el desarrollo de la Industria Naval, Marítima y Fluvial – COTECMAR, más específicamente en el Departamento de Producción de la Gerencia de Mantenimiento y Reparación de Buques en la Planta; con el fin de conocer el porcentaje de tiempos ociosos en los procesos productivos ejecutados e identificar las principales causas que lo genera, a través de la estimación de la proporción de tiempo dedicado a actividades específicas durante cierto periodo de tiempo, empleando para ello la toma de observaciones instantáneas de las áreas de trabajo y utilizando el muestreo probabilístico para generalizar los resultados del estudio.

Palabras claves: Muestreo de Trabajo, Muestreo Probabilístico, Tiempos Ociosos.

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About Work Study

According to the International Labour Organization (ILO), work study is the It is the systematic examination of methods of carrying out activities so as to improve the effective use of resources and to set standards of performance for the activities being carried out.

Work study then aims at examining the way an activity is being carried out, simplifying or modifying the method of operation to reduce unnecessary or excess work, or the wasteful use of resources, and setting up a time standard for performing that activity. The relation between productivity and work study is thus obvious. *(International Labour Organization, 1996).*

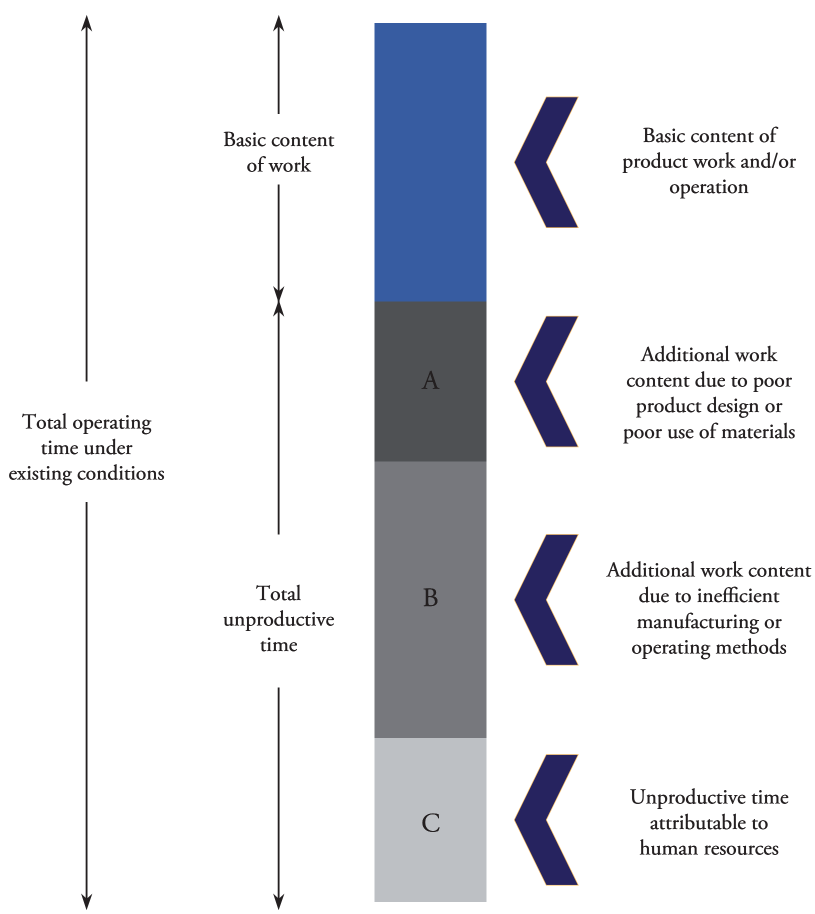
To carry out such examination, the reference object is marked by the total time or a job, defined as "the time taken by a worker or a machine to carry out an operation or to produce a given quantity of a certain product." Fig. 1 shows how operational time is made up.

Work study is developed from the interrelation of several techniques, where special importance is given to the **study of methods** and **work measurement**.

On the one hand, the study of methods is the recording and systematic critical review of the techniques to carry out activities in order to make improvements.

On the other hand, work measurement is referred to as the application of techniques to determine the time taken that is invested by a qualified worker to carry out a task at a defined standard of performance.

Fig. 1. How Total Time of a Work is Made Up



The strong connection between these two techniques results in an important input to make decisions aimed at the improvement of productivity in organizations.

Work Measurement

This study will emphasize in one of the two main techniques used in work study. Specifically, it will focus on work measurement.

According to the ILO, work measurement can be used to investigate, reduce and finally eliminate ineffective time.

In this context, ineffective time is understood as that time in which productive work is not executed, for any reason.

According to the foregoing, work measurement is the means whereby the time invested in executing an operation or a series of operations can be measured in order to highlight the ineffective time and separate it from the productive time.

Work measurement is governed by a basic procedure comprised of six stages. It starts with the selection of the work that will be the subject of the study to then make the recording of the data related to the circumstances under which the work is carried out. The systematic procedure continues with the review of the data recorded and the details of the elements with a critical sense[1], providing this information to develop the work measurement for each element. The fifth stage refers to the compilation of time standards for the operation that will allow for the definition (final stage) of the series of activities and the method of operation with precision. Fig. 2.

The International Labour Organization clarifies that the six stages must be followed completely if there is a desire to set standard times. On the contrary, if there is only a desire to find out about the ineffective times, only the first four stages need to be executed.

[1] The purpose is to determine if the most efficient methods and movements are being used and to separate the ineffective or strange elements from the productive elements.

Work measurement is supported in certain techniques to meet its purpose. These are: Activity Sampling, Structure Estimation, Time Study and Predetermined Time Standards. Fig. 3.

Fig. 2. Systematic Procedure for Work Measurement - ILO

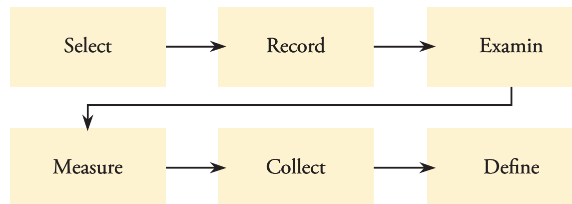
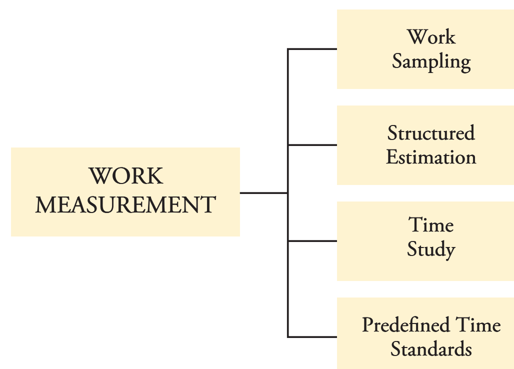


Fig. 3. Techniques of Work Measurement



Work measurement may be carried out through the implementation of one of the techniques available or also through the selection of a combination of the same.

Next, an emphasis will be made on the technique selected during the research conducted herein: *Work Sampling.*

Work Sampling

Work sampling is a technique developed in England by the statistician L.H.C. Tippet in 1934 who estimated the percentage of time that each worker dedicates to carry out several tasks, making random observations that record the activity that is being carried out in that moment. *(Bañegil Palacios, and others, 2005).*

It is a technique used for work measurement that through the statistic sampling and recollection of a large number of observations taken at random is capable of determining the percentage of appearance of an activity, the productive time of a person or machine and its causes, and the standard time of work, among others.

Work sampling, also known as "activity sampling" or "instant observation method" arises as an alternative to the continuous observation as the one seen in the time study, given that to carry out this type of studies, a large investment in human resources is needed especially destined for the development of this task *(International Labour Organization, 1996)*. Therefore, it is more practical to carry out a series of paths in which a sufficiently large number of observations that allow establishing the existence of a good probability that said observations reflects the real situation with certain level of trust and margin of error is taken.

Work Sampling Common uses, Advantages and Disadvantages

Three of the most common uses of work sampling *(De la Paz González, 2014)* are:

- **Determination of the percentage of use of a man or a machine:** It is accomplished by the establishment of a portion of productive and inefficient time allowing to take measures on the main causes of delay and suspension of work.
- **Determination of allowances:** Enables the definition of labor standards taking into account allowances for personal reasons and unavoidable delays.
- **Time Standard Calculation:** The time required is found so that the qualified and trained operator carries out a job considering that it is developed at a normal rhythm of work.
- These typical uses are feasible given the advantages that support the technique (*Garcia, 2005)*, among which are:
- They do not require continuous observation by an analyst for long periods of time.
- Reduces the work time.
- Generally uses less man-hours to develop the study.
- The operator is not subject to pressure for being observed for long periods of time with a stopwatch.
- One observer may easily study the operations of a group of workers.

Nevertheless, literature indicates that there are limitations that constitute a disadvantage for the technique. These are:

- It is not cost-effective for the study of only one man or machine operation.
- It is usually not cost-effective to determine the standard time of repetitive operations with very short cycles.
- It does not yield very detailed information of the elements that form an operation such as the study of times.
- It does not provide a detailed record of the method used by the operators.
- It is more difficult to explain to workers and managers.

Work Sampling in Cotecmar

The work sampling technique at the Science and Technology Corporation for the Development of the Naval, Maritime, and River Industry - COTECMAR, has its most recent and relevant background in the study called “Improvement of the situation in the ship-repair direction of Cotecmar” *(Fraunhofer IPA, 2013)* and the university internship program "Measurement of Productivity in Ship Repair Processes" *(Porto, 2013)*, whose main objective was to obtain statistical data that supported the development of a production planning tool.

The theory of these studies was based in that when taking into account the results of all the activities observed, predictions could be made about the estimated production time including probable additional activities that could appear during the repair project. This through the collection of data from the application of Work Sampling and the review of historical data such as estimated and executed man-hours in finalized projects.

With these studies, it could be established that the time for the development of naval ship repairing projects is extended in comparison with the time initially projected for each project due to certain delays in the productive process.

Likewise, it was determined that the problems that cause such delays were common at a general level in the Shipbuilding Industry.

Lastly, the Fraunhofer IPA Institute determined that the idle times in the repairing area of the corporation were approximately 30% of the total work time, a number that was above the international average for companies of the same industry.

New Implementation of Work Sampling at Cotecmar

An initiative focused on updating the Idle Times indicator determined in 2013 by Porto and Fraunhofer IPA was implemented within the context of the research, development and innovation project "Strengthening of Productive Processes Aimed at Increasing Productivity in Repairs" (2015) directed by the Science, Technology and Innovation Department.

To determine the methodology for the implementation of the work sampling technique developed in this research, a review of the literature was made *(Krajewski, and others, 2000)*, as well as taking into account the steps used during the year 2013 in the study developed by the Fraunhofer IPA German Research Institute, adapting them to the needs of the project herein referred to.

The foregoing provided structure to the methodology used by the researches. This is presented below:

Methodology for the Implementation of Work Sampling

The assimilated methodology was comprised of a series of 8 steps.

Step 1 - Selection of the Study Unit: The work sampling technique was defined to the procedures and activities carried out by the Production Department and its corresponding divisions, which are a part of the facilities of Cotecmar's Mamonal Plant.

Step 2 - Definition of the study objectives: Three objectives were defined:

1. Replicate the Work Sampling methodology carried out by the corporation during the year 2013 to make a new measurement of ship repairing and maintenance works.
2. Analyze the data that resulted from the measurements generated by the Work Sampling and identify the current value of Idle Times for repairing and maintenance activities.
3. Compare the results of the data analysis that will be carried out with the reference indicator defined in 2013 about the Idle times to observe the behavior and evolution of the same.

Step 3 - Classification of the activities to be observed: Enabled the classification of the observations for taking measurements. These were grouped by productive division (Figs. 4, 5, 6, 7 and 8)

Fig. 4. Boatyard Division Classification

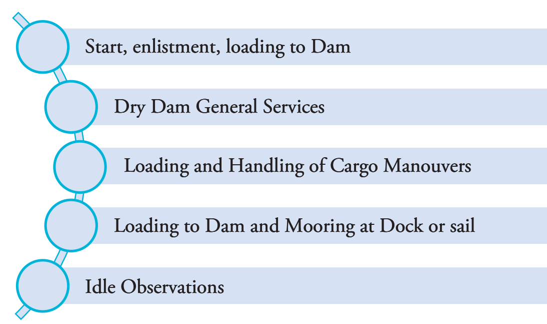


Fig. 5. Paint Division Classification

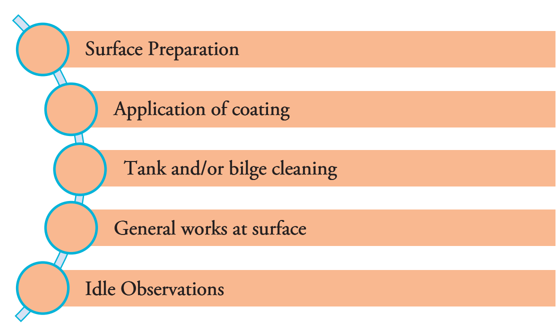


Fig. 6. Welding Division Classification

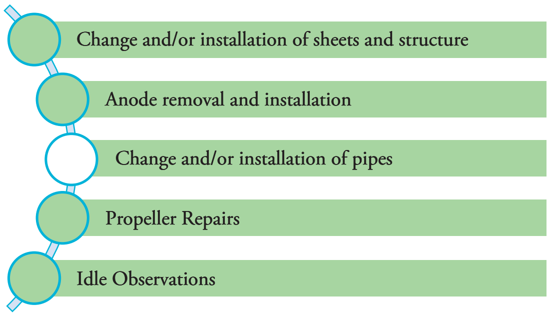


Fig. 7. Mechanical Division Classification

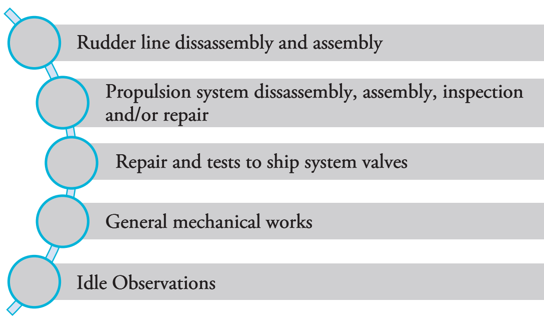
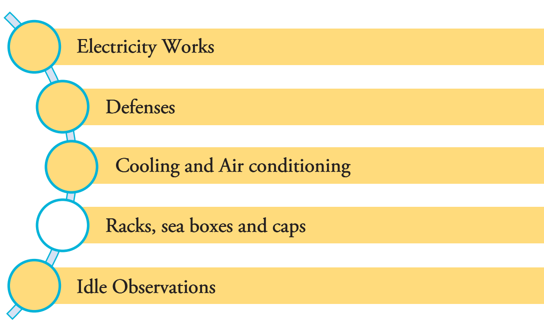


Fig. 8. Other Observations Classification



Step 4 - Sampling Calculation, Level of Reliability and Precision: In addition to establishing the reliability and precision levels of the new work study, the assumptions used during the previous measurement are used *(Porto, 2013)* in order to establish an efficient comparison between the results.

The number of observations was calculated as follows:

$$n' = \frac{1{,}96 * p * (100 - p)}{(f)^2} \tag{1}$$

Where:

n' = Number of observations required
p = Percentage of activity of larger amount or more representative with respect to the total
f' = Desired precision or error standard of the maximum permissible proportion

Taking as a start point a desired precision (*f'*) 2.5%, a margin of error of 5% for a level of reliability (*Z*) of 95% (equal to 1.96 of the normal curve) and *p*[2] = 20%, a size of the sample (observations) was determined to be equal to:

$$n' = \frac{1{,}96 * 20 * (100 - 20)}{(2{,}5)^2} = 984$$

Step 5 - Definition of the frequency of observations: It was carried out using the following formula:

$$R_T = \frac{n_T}{n_R} = \frac{n'}{(T - n_R)} \tag{2}$$

Where:

R^T = Number of daily trips by observer
n^T = Number of daily observations, represented by the reason *n'/T*; where (*n'*) is the number of total observations required to meet the sampling objective; and (*T*) is the number of average days of execution or duration of a repairing project.
n^R = Number of work stations observed in each "Work Sampling Analysis".

Replaced in the second equation[3], the result was:

$$R_T = \frac{n_T}{n_R} = \frac{n'}{(T - n_R)}$$

$$R_T = \textit{18 recorridos}$$

[2] This value of p = 20% was defined taking into account historical data of repairing projects where the most representative activity with said proportion was the welding activity.
[3] As with the sampling calculations, the assumptions applied in the study made during the year 2013 were used, where it was established that the average time of duration of one repairing project is 57 days; likewise, it was determined that only one work station would be taken comprised of the grounding position (in which the ship is in) and the workshops.

Step 6 - Observations format design: The format includes six pages, four of which belong to each one of the divisions that emphasize the main procedures executed by them (shown in Figs. 4 to 8); another page belong to the procedures classified as "others" given that they are developed jointly by two or more divisions; and lastly, a page dedicated to the comments that could arise from the observers during the trips and that could help for the analysis of the work sampling.

Step 7 - Collection and Recording of Observations: For the collection and recording of the observations there was the support of two observers that made 10 trips during the day shifts and with one fixed time interval of 50 minutes during the period of time between September 22 and November 12, 2015.

The following pauses were provided as mandatory for the observers to be able to carry out their job:

- The observers need to know each one of the processes made by the divisions that are a part of the Production Department of the Mamonal Plant in order to carry out the collection of observations optimally.
- The observer must get close to the work area (workshops and grounding position) walking towards a fixed location where the activities are being carried out, make the observation and record the facts in the collection forms.
- One observation corresponds to one operator seen one time, that is, if the observer arrives during a trip to the work area and observes ten operators, the observer will have 10 observations during this trip, classifying the observations according to the different processes.
- If the person is idle, the observer shall determine the reason for such idle observation in a collection form.
- Where possible, the observes shall memorize these observations in order to record them once he leaves the work area in order to minimize the sense of pressure of the operators that are being observed.
- Likewise, the observers must try to change the paths of the trips by alternating them when these include work in workshops and grounding position.

Step 8 – Work Sampling Data Analysis: The analysis of data collected through the observation collection forms used a template in which said data was included obtaining information and graphs about: the cumulative proportion of each one of the activities as well as the idle times within the total observations; the daily proportion of each one of activities within the observations of the day; and the evaluation of the activities classified as idle by division and in general during the study.

Work Sampling Implementation Results at Cotecmar

The results presented below were obtained from the work measurement of five repairing projects (Mahury, Spence, Macondo, Roxana Trader and San Andrés) executed by the Production Department of the Mamonal Plant, during approximately two months in the year 2015.

After the completion of such measurements, a general average of idle times of 24.23% was obtained in accordance with the observations taken from the five projects of the study. Table 1 and Table 2.

Fig. 9. Mahury Project

Fig. 10. Roxana Trader Project

Fig. 11. Spence Project

Fig. 12. Macondo Project

Table 2 shows the start and end date of the application of the Work Sampling technique for each one of the projects. In addition, the number of observations taken classified by division is observed, as well as the proportion (percentage) within the total of the measurements taken. Lastly, the total number of observations taken in each project is shown, as well as the number of idle observations contained within the total and lastly, the percentage of idle observations as well as the general average of all the repairing works of the sampled ships.

General Analysis of the Results

The investigation and the data obtained from such investigation allowed to determine the percentage distribution of the processes developed by the different productive divisions at the time of said investigation. Fig. 13.

The findings reveal that the largest proportion of works belongs to those related to welding (32.5%), followed by surface works (19.7%) and mechanical (17.5%). Also, the findings show that the inactive and idle times had a value of 24.2%.

This value is an improvement of approximately 5.8% with respect to the base line of the 2013 study, placed at 30%. This situation is due to the efforts made by the Management of the

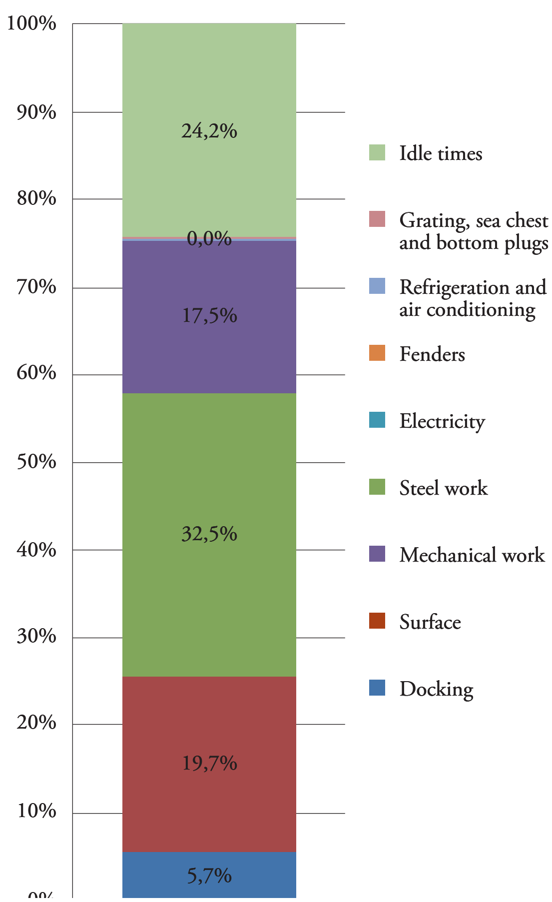
Table 1. Characterization of work sampling measurements by repairing project

Ship	Type	Start Date	End Date	Duration (days)	Observations
MAHURY	Dredge	22/09/2015	28/10/2015	36	3745
SPENCE	Tug	29/09/2015	12/11/2015	44	4640
ROXANA TRADER	Cargo Ship	01/10/2015	06/11/2015	36	3668
MACONDO	Cargo Ship	14/10/2015	03/11/2015	20	2248
SAN ANDRÉS	Cargo Ship	26/10/2015	05/11/2015	10	747

Table 2. Work Sampling Measurement Results

SHIP	MAHURY			MACONDO			SAN ANDRÉS			ROXANA TRADER			SPENCE			
Start date of observations	22/09/2015			14/10/2015			26/10/2015			01/10/2015			29/09/2015			
End date of observations	28/10/2015			03/11/2015			05/11/2015			06/11/2015			12/11/2015			
		#	%		#	%		#	%		#	%		#	%	
Active observations	DVARD	176	4,70	DVARD	172	4,59	DVARD	97	2,59	DVARD	259	6,92	DVARD	146	3,90	
	DVPIN	447	11,94	DVPIN	653	17,44	DVPIN	337	9,00	DVPIN	998	26,65	DVPIN	542	14,47	
	DVSOL	1756	46,89	DVSOL	580	15,49	DVSOL	13	0,35	DVSOL	616	16,45	DVSOL	1929	51,51	
	DVMEC	216	5,77	DVMEC	430	11,48	DVMEC	109	2,91	DVMEC	968	25,85	DVMEC	892	23,82	
	OTROS	4	0,11	OTROS	2	0,05	OTROS	6	0,16	OTROS	10	0,27	OTROS	44	1,17	
Idle observations	DVARD	49	1,31	DVARD	36	0,96	DVARD	32	0,85	DVARD	68	1,82	DVARD	21	0,56	
	DVPIN	284	7,58	DVPIN	199	5,31	DVPIN	142	3,79	DVPIN	322	8,60	DVPIN	209	5,58	
	DVSOL	674	18,00	DVSOL	123	3,28	DVSOL	0	0,00	DVSOL	199	5,31	DVSOL	571	15,25	
	DVMEC	139	3,71	DVMEC	53	1,42	DVMEC	11	0,29	DVMEC	228	6,09	DVMEC	259	6,92	
	OTROS	0	0,00	OTROS	0	0,00	OTROS	0	0,00	OTROS	0	0,00	OTROS	27	0,72	General
Total number of observations	3745			2248			747			3668			4640			15048
Total number of idle time observation	1146			411			185			817			1087			3646
% Idle Time	30,60%			18,28%			24,77%			22,27%			23,43%			24,23%

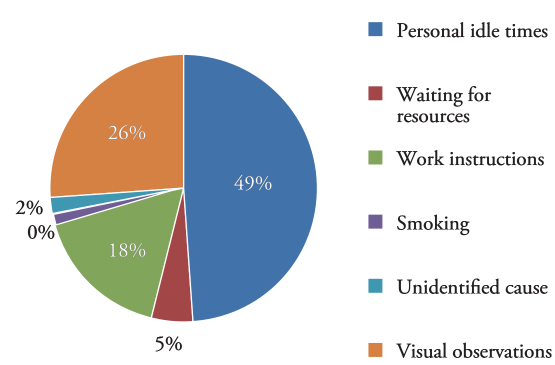
Fig. 13. Percentage distribution of general processes



Mamonal Plant to improve the productivity in its activities.

The Idle Time indicator also was characterized from the sampling made. Fig. 14.

Fig. 14. Percentage characterization of general idle times



From Fig. 14 it can be observed that the causes mostly attributable to the presence of Idle Times in the activities carried out is due to the personal allowance times (49%) attributable to each worker. Contemplative observations (26%) and waiting for work instructions(18%). This represents a total of 93% of the possible causes that generate idle times.

Conclusions

The Idle Time indicator was reduced in 5.8% from 30% in the year 2013 to 2.2% during the year 2015. Which results in a high reduction in the comparison with the Corporation's expectation from the implemented continuous improvement techniques (5s y Kaizen), and thus it would be important to study in more depth the possible causes and collect good practices from different divisions in order to conduct an internal benchmarking.

Although this study classifies the reasons for the idle times to occur and the proportion within the same, it does not provide solutions to reduce such idle times. Therefore, it is necessary to investigate in detail the reasons found and seek ways to attach them in order to reduce the idle times of the Corporation.

To be able to carry out improvement actions or proposals in the future, it is important to support the Production Department with plans aimed at process standardization. Inasmuch as every day it is possible to find solidity due to standardized processes, it will be possible to take data and measurement of activities, processes and procedures more centrally and close to reality, that will be translated in the identification of correct indicators o performances for the different jobs.

Under the premise *"what cannot be measured cannot be controlled and what cannot be controlled cannot be improved"*, for a process characterized by so much complex and dynamic variables, such as the repairing of ships at Cotecmar, it is necessary to create a solid measurement system that provides evidence of the critical points of the activity. The information that results from these indicators should be visible in such a way so that those involved to a greater or lesser extent may know them and set their goals in terms of the indicator.

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Damaged warship stability tests based on ANEP-77: A case study for F-110

Pruebas de estabilidad en buques de guerra averiados con base en ANEP-77: Estudio de caso para F-110

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Abstract

Stability tests are a core part of a hydrodynamics warship design. The acquired knowledge from the hydrodynamics model basin will affect her lifespan. Particularly, a safety assessment of damaged ships, which considers environmental conditions such as waves and wind, is critical in future operations. Over the last decade, a significant amount of experience has been gained associated with predicting the capsize behavior of intact and damaged naval vessels, and the main objective of this paper is to provide insights into different relevant physical aspects to prevent the capsizing of damaged ships in waves following the Naval Ship Code (NSC) or ANEP-77 rules. Currently, the Royal Navy of Spain is developing the future F-110 frigate class and carried out model tests at Canal de Experiencias Hidrodinámicas de El Pardo (CEHIPAR) for optimizing the forms of body hulls. Among these dynamic experiences, the most critical are the damage stability tests. Although a safety criteria of damaged ships that considers environmental conditions such as waves and wind has not yet been developed, NATO and the European maritime classification societies have developed guidelines for safety assessments such as the ANEP-77. This code contains damage scenarios and environmental conditions.

Key words: Naval Ship Code, ANEP-77, damage stability, ship safety assessment, damage scenarios, dynamic phenomena, collision, grounding, damage safety criteria, model tests.

Resumen

Las pruebas de estabilidad son una parte fundamental de un diseño de busques de guerra hidrodinámicos. El conocimiento adquirido de la cuenca del modelo hidrodinámico afectará su vida útil. En particular, una valoración de la seguridad de las naves averiadas que considera las condiciones ambientales como el oleaje y el viento, es crítico para operaciones futuras. Durante la última década, una experiencia significativa ha sido adquirida respecto de la predicción del comportamiento de la zozobra de buques militares averiados e intactos y el principal objetivo de este ensayo es dar perspectivas sobre los diferentes aspectos físicos relevantes para prevenir la zozobra de naves averiadas en olas mediante el seguimiento del Código de Buques Navales (NSC) o normas ANEP-77. Actualmente, la Armada Real de España esta desarrollando la futura clase de fragata F-110 y realizó pruebas modelo en el Canal de Experiencias Hidrodinámicas de El Pardo (CEHIPAR) para optimizar las formas de cascos de cuerpo. Entre estas experiencias dinámicas, las más críticas son las pruebas de estabilidad de averías. Aunque el criterio de seguridad de las naves averiadas que considera las condiciones ambientales tales como oleaje y viento no ha sido aún desarrollado, la OTAN y la sociedades de clasificación marítimas europeas han desarrollado guías para la evaluación de seguridad tales como la ANEP-77. Este código contiene escenarios de averías y condiciones ambientales.

Palabras claves: Código de Buques Navales, ANEP-77, estabilidad de averías, evaluación de seguridad de las naves, escenarios de daños, fenómenos dinámicos, colisión, naufragio, criterio de seguridad de averías, pruebas modelo.

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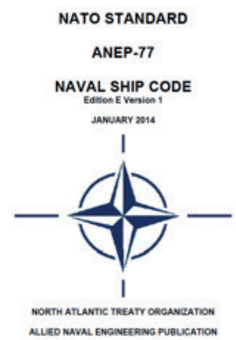
Fig. 1. Virtual picture F-110 Frigate class (MDEF, 2016) and ANEP-77 Edition



Introduction

The future F-110 frigate class is under final design definition phase and has further developed and matured the design baseline established at the end of the feasibility phase. The ship's general arrangement, propulsion machinery and key systems had been finalized, with only minor details still outstanding. In the latest interaction, the F-110 design has a length of 145m, a beam of 18,6m, a draught of 5,5m and a displacement of up to 6.000Ton. Maximum speed is greater than 26kt, CODELAG propulsion machinery with a cruising speed of 17kt and a 4.100 nautical miles range at 15kn. Model tests will validate the hydrodynamic and sea keeping properties of the preliminary design selected for the frigate. The Spanish Navy's requirements for the first-of-class will be available in the 2023-24 timeframe.

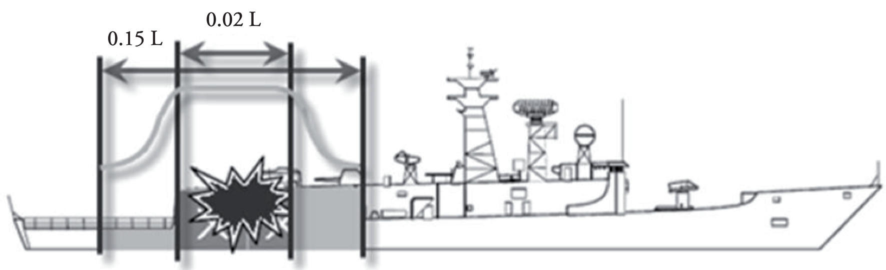
It is logical to think, since the sea is common for every ship, that merchant and warships are susceptible to the same type of accidents (groundings, collisions, fires, loss of stability…) and encounter the same adverse weather conditions (seafaring, fog…). On the other hand, due to the purpose for which they have been projected, warships have to deal with additional threats like hostile actions of different nature and intensity, representing all a potential risk to their stability and buoyancy.

In the United Nations Convention on the Law of the Sea (UNCLO), article twenty-nine defines a warship as "a ship belonging to the armed forces of a State bearing the external marks distinguishing such ships of its nationality, under the command of an officer duly commissioned by the government of the State and whose name appears in the appropriate service list or its equivalent, and manned by a crew which is under regular armed forces discipline." The International Convention for the Safety of Life at Sea (SOLAS), in its rule three "Chapter I – General Provisions", states that its rules do not apply to warships and ships that transport troops. So, warships are exempt from most of the laws of the merchant ships (Fig. 2), and as such, both the international and national levels have directed the safety of naval surface ships independent of statutory organizations. But there are exceptions to this; vessels can be classified and certified by Classification Societies (SC) or flag authorities and there are some aspects of the statutory legislation that warships have to consider. Thus, development of rules for warships or Naval Ship Rules by various SC is the most important contribution to work in this area.

Admitting that there is no equivalent of the International Maritime Organization (IMO) for warships, the only recognized navy specifications, Stability DDS-079-1 (Fig. 3), the North Atlantic Treaty Organization (NATO) established a decade ago some teams of specialists in the Naval Ship Classification Association (NSCA) and a partnership for classification of warships. These teams of specialists have been entrusted with the preparation of the Naval Ship Code (NSC) and a benchmark of international standards for ships. This promotes greater transparency and consistency in safety standards for warships. This code aims to fill the gap by providing the framework for armed forces security that has

Fig. 2. Capsizing of a fishing boat in front of Libyan coast (Marina Militare Italiana, 2015)

Fig. 3. Damage extension DDS-079-1 (US Navy, 1975)



achieved acceptable levels of safety and will be the link between IMO, the Classification Societies and Navies. The development of this code provides a cost-effective framework for a naval surface ship safety management system based on and benchmarked against IMO resolutions. The specialists' teams established a goal-based approach to the development of the code, developing each chapter in turn. The Naval Authority Knowledge Management Office (NAKMO) website contains the latest version and its corresponding guide, and NATO adopts the publication as an Allied Naval Engineering Publication ANEP-77. The current version (F) was published on August 2014.

Stability Requirements Evolution

From 2009 to 2014, the evolution of some aspects of the ANEP-77 Ed. F in comparison to its 2009 edition is substantial, with a major restructuring to the Table of Contents. Chapter 3 of the ANEP-77 is titled "Buoyancy, Stability and Controllability" and has goals to provide an adequate reserve of buoyancy *(NSA, 2012)* in all foreseeable intact and damaged conditions, an adequate stability to avoid capsizing, permit embarked persons to carry out their duties and protect the embarked persons and essential safety functions in the event of foreseeable accidents and emergencies. Therefore, the primary goal of this chapter has been set to provide the ship with the ability to remain afloat in an upright orientation in all operating conditions including loading, heavy weather and applied "foreseeable" disturbances including cases of damage causing loss of watertight integrity. Also, this chapter and the corresponding explanation guide with its solutions presents the performance requirements

Table 1. Environmental test conditions (ANEP-77, 2014)

Service Class	Operational			Survival			Damage		
	Wind Speed		Sig. Wave Height (m)	Wind Speed		Sig. Wave Height (m)	Wind Speed		Sig. Wave Height (m)
	Nominal (B*Fort)	Design (knots)		Nominal (B*Fort)	Design (knots)		Nominal (B*Fort)	Design (knots)	
Ocean Unlimited	9	70	6.0	12	100	17.7	26	39	2.5
Ocean Limited	8	60	6.0	10	80	11.2	26	39	2.5
Offshore	7	50	4.0	8	60	6.2	24	36	2.2
Restricted Offshore	6	40	2.5	7	50	4.3	22	33	1.8
Protected Waters	5	30	1.25	6	40	2.5	20	30	1.5
Smooth Waters	5	30	0.5	6	40	0.8	20	30	0.5

and the verification methods about intact and damage stability *(Pérez and Riola, 2011b).*

This is the reason why this chapter is so important for the hydrodynamics model basin naval architects. To increase the safety of damaged ships, designers (Surko, 1994) focus more on damage mitigation than accident prevention. The damage mitigation requires prediction of the damage stability (Sarchin and Goldberg, 1962), the structural integrity, and the motion analysis for damaged ships in waves. Furthermore, pertinent ANEP-77 damage scenarios are developed to the damage safety criteria.

There are some notorious variations in the drafting of Regulation 2 (Watertight Integrity) and 3 (Reserve of Buoyancy) deleting the prescriptions related to maneuverability contained in order to create the new Regulation 5 (Maneuverability). But, without any doubt, the most remarkable change happened in Regulation 4 (Reserve of Stability) where only minor general requirements about stability were specified in 2009 Ed. of NSC and now in Ed. F a variety of several goals for the study of intact stability were chosen to be included by the people responsible of the project. The specialists' teams established a goal-based approach to the development of the code, developing each chapter in turn.

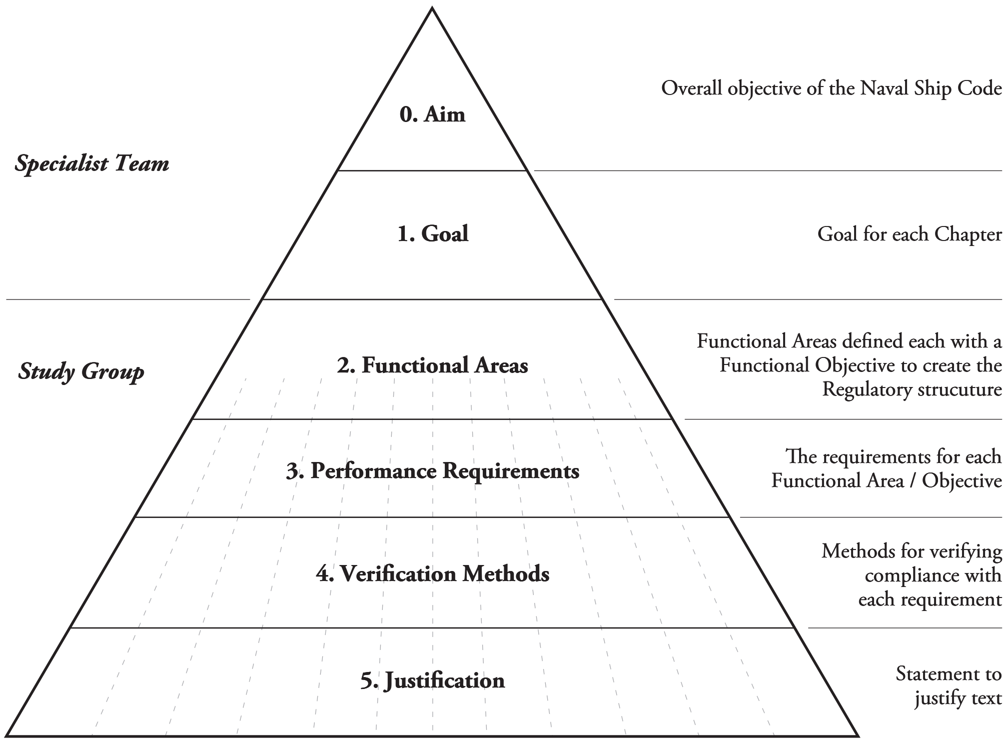
The basic principle of a goal-based approach is that the goals should represent the top tiers of the framework, against which a ship is verified both at design and construction stages, and during ship operation. This enables the ANEP-77 to become prescriptive if appropriate for the subject, or remains at a high level with reference to other standards and their assurance processes. The goal-based approach also permits innovation by allowing alternative arrangements to be justified as complying with higher-level requirements. The increasing width of the triangle as the ANEP-77 descends through the tiers implies an increasing level of detail *(Riola and Pérez, 2009).*

In ANEP-77, the goal based standards approach is anchored in five tiers outlined as follows:

- Tier 0 – Aim (philosophies and principles)
- Tier 1 – Goal
- Tier 2 – Functional areas
- Tier 3 – Performance requirements
- Tier 4 – Verification methods
- Tier 5 – Justification

Therefore, the goal-based approach provides a systematic framework for certification of a ship to meet the goals of ANEP-77. Performance requirements are defined based on the Concept of Operations (CONOPS) and verified using appropriate criteria. Although this approach contained in ANEP-77 provides for implementation of FSA approaches, it is not the same as an overarching design for safety approach in that ANEP-77 allows a Naval Administration to apply FSA in the Tier 4 verification of specific performance requirements associated with defined

Fig. 4. NSC goal based approach (NSA, 2014)



functional areas. Prescriptive standards can still be used to verify the goals *(NATO, 2010)*.

Naval Ships Damage Scenarios

When a ship accident occurs because of several causes, both the hull and structures are damaged. These damages cause the ship to flood, which can lead to sinking, capsizing or breaking up. The damage conditions used to predict the expansion of and loss due to damage are composed of a combination of the ship dimensions, sea states, and damage configurations, such as the location and extent of a damage hole. The ship dimensions can be represented by the loading conditions

Table 2. Summary table of damage categories (ANEP-77)

	Damage Category A (DCA)	Damage Category B (DCB)	Damage Category C (DCC)
Sphere	1m (radius)	4m (radius)	10m (radius)
Cube	2m (edge)	8m (edge)	20m (edge)
Horizontal prism	4m (length) 0,5m (triangular edge)	16m (length) 2m (triangular edge)	40m (length) 5m (triangular edge)
Vertical prism	4m (height) 0,5m (triangular edge)	16m (height) 2m (triangular edge)	40m (height) 5m (triangular edge)
Peak temperature	100ºC	200ºC	300ºC
Time to rise to peak temperature	5 minutes	10 minutes	20 minutes
Peak temperature duration	10 minutes	20 minutes	30 minutes
Time for temperature to revert to normal	50 minutes	100 minutes	20 minutes

and geometrical characteristics such as the hull, length, breadth, draft, KG, and compartment arrangement, and the environmental conditions refer to wind and wave conditions such as height, length and period, and of course, the angle of the wave heading that has to be taking into account also.

The damage categories (Table 2), in ANEP-77, are based on defined shapes:

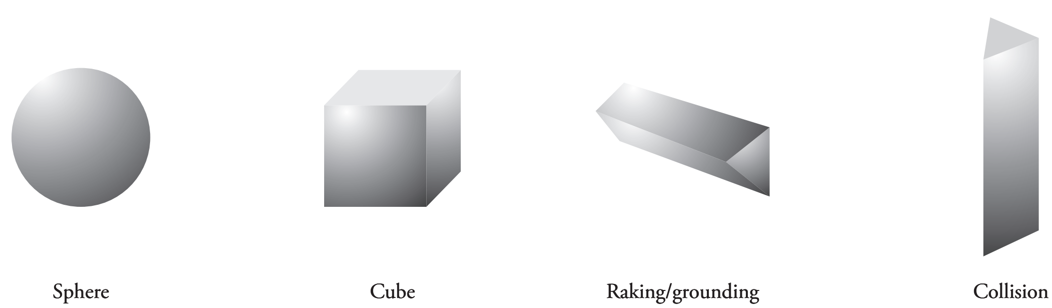
- Collision. To be used in the correct vertical orientation to describe the extent of collision damage from the bow of another ship, the apex representing the maximum penetration.
- Raking/grounding. To be used in the appropriate horizontal orientation to describe the extent of raking or grounding damage, the apex representing the maximum penetration.
- Cube. To be used to define the volume directly affected by fire and which may change in shape to fit the compartment.
- Sphere. To be used for explosions. For explosions detonating against the exterior of the hull, half the sphere to be used.

Collision: collision tests are done to every merchant ship meeting the SOLAS rules of the IMO. As it was mentioned in the introduction of this publication, *warships are exempt from most of the laws of the merchant ships*. This means that although collisions are not specifically damage related directly with the naval combat, warships shall be also tested to resist a collision situation. In ANEP-77, specifically in Chapter IX NAVIGATION, Regulation 9 Collision Avoidance, amendments to COLREGS *(International Regulations for Preventing Collisions at Sea, 1972)* from 2007 onwards have been incorporated/reviewed and included in this edition.

Grounding: it is not common to find a frigate sailing in swallow waters, considering the risks this represents, not so with littoral combat ships, amphibious ships or patrol boats. Grounding damage cases are described using the longitudinal location of the damage and the number of spaces affected. Using triangular prism shape specified on the ANEP-77 Code, the author can simulate which compartments of the ship have been affected by the accident. The damage extents are defined as the longitudinal damage length and width, which are determined by the ships speed, the thickness of the steel hull or structural details as transverse web spacing, and the underwater stone characteristics as height, hardness or toughness.

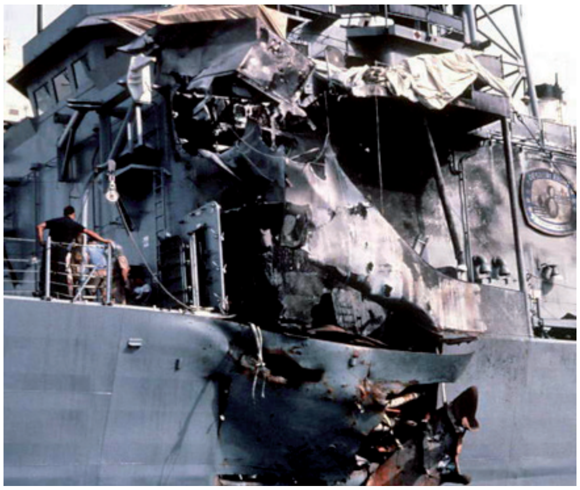
Weapons Damages: Fire and Explosions (cube and sphere cases): For naval ships, it is necessary to consider the damage of the attack caused by enemy weapons in addition to collision and grounding. At the moment, design rules for naval ships apply the criteria only to evaluate the adequate damage stability performance based on the righting arm curve but continuous research has focused on this area in recent years *(Pérez and Riola, 2011a)*. Of course, it is impossible to predict the damage size, extension and location because it mainly depends on the success of the enemy weapon. As the ANEP-77 is to provide a level of safety appropriate to the role of the ship and benchmarked against statute while taking into account naval operations, it is necessary to define the degree of survivability in a way that can be taken into account in the development of the different chapters. As an example, the main

Fig. 5. Different damage shapes (ANEP-77, 2014)



difference between the fire safety approach from a naval and civilian shipping point of view is that SOLAS considers the risk of fire based on the function of each compartment whereas for naval ships, hostile acts may result in fire anywhere on the ship, both externally and internally.

Fig. 6. USS Stark (Weis, 1987)

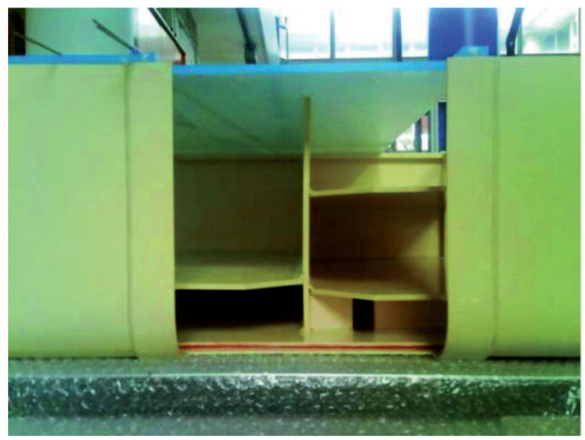


Ship Dynamics Laboratory

The future Frigates F-110 model tests can be carried out in the sea keeping basin of El Pardo Model Basin (CEHIPAR) close to Madrid. The basin has a sixty flaps wave maker, a computerized carriage (CPMC) and the following dimensions: 150 meters long x 30 meters width x 5 meters depth. IMO survivability tests, European Commission researches and the Stockholm Agreement supplement were carried out over recent decades, have provided widely recognized and experienced personnel in the maritime security field.

In order to reproduce the damage stability tests in the dynamic lab, a rigid scale model, a wave spectrum and a data acquisition system are necessary. The model should be as large as possible, since details of damaged compartments are easier constructed in larger models and the scale effects are reduced. It is therefore recommended that the model length is not less than that corresponding to a 1:40 scale. The data acquisition system consists mainly in an optical tracking system able to gatherthe information sent from the free model moving on the waves emitting light diodes. To maintain the same hydrostatic properties, a fiberglass model is built in a scale with the corresponding scale characteristics. It is required that the model is instrumented so that its roll, heave and pitch motions as well as its heel, sinkage and trim attitudes are monitored and recorded throughout the test. All the significant appendages such as rudders and keels are fitted and the inner damaged area compartmentation was made as realistic as possible. It is also important to ensure that the damaged compartments are modeled as accurately as practicably possible to ensure that the correct volume of floodwater is represented.

Fig. 7. Inner flooding compartments



The model, considering the damages assumed, must be as thin as practically possible to ensure that the amount of flood water and its center of gravity is adequately represented. It is recognized that it may not be possible for the model hull and the elements of primary and secondary subdivision considering the damage to be constructed with sufficient detail and due to these constructional limitations it may not be possible to accurately calculate the assumed permeability of the space and the percentage of volume of the space, which may be occupied by seawater if the space is flooded. Typical values from the SOLAS are 0.95 for empty spaces, tanks, and living spaces, 0.85 for machinery spaces and 0.60 for spaces allocated to stores.

The vertical extent of the model can affect the results when tested dynamically, so it is required that the ship is modeled to at least three superstructure standard heights above the freeboard deck so that the large waves of the wave train do not break over the model. After measuring the damaged draughts it may be necessary to make adjustments to the permeability of the damaged compartment by either introducing intact volumes or by adding weights. This, to ensure that the model motion characteristics, the intact GM and the mass distribution are verified. The transverse radius of gyration of the actual ship is not to be taken as being greater than 0.4B and the longitudinal radius of gyration is not to be taken as being more than 0.25L. The balance period will be defined as follows:

$$T = \frac{2\pi \cdot K}{\sqrt{g \cdot GM}} = \frac{2{,}006 \cdot K}{\sqrt{GM}} \qquad (1)$$

Where K is the radius of inertia of the ship. It is normal to define this ratio as a beam function:

$$T = \frac{f \cdot B}{\sqrt{GM}} \qquad (2)$$

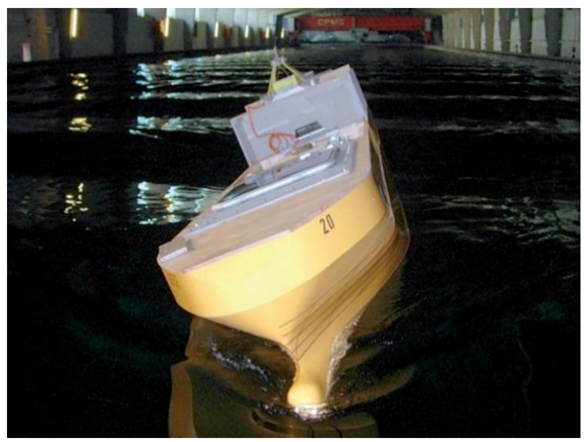
f values depend on the type, load case and general arrangement of the ship.

It is required that for every test run, the wave spectrum is recorded and documented. Measurements for this recording are to be taken in the immediate vicinity of the model and also near the wave maker machine. Extensive research carried out for the purpose of developing appropriate criteria for new vessels has clearly shown that in addition to the GM and freeboard being important parameters in the survivability of ships, the area under the residual stability curve up to the angle of maximum GZ is also another major factor. Consequently, in choosing the worst ANEP-77, damage for compliance with the requirement of the worst damage is to be taken as that which gives the least area under the residual stability curve up to the angle of the maximum GZ (Fig. 12).

Dynamic Phenomena Basin Test

Frigate design scale model will be verified in the following tests on the model basin: dynamic rolling, parametric excitation, resonant excitation, impact excitation, transient flooding, broaching, survivability test, etc. In order to define the boundary conditions of each test, the specifications of ANEP-77 *Environmental test conditions (refer Table 1)* will be used, meeting the parameters of the three different conditions specified *(Operational, Survival or Damage)*. Furthermore, the wave spectrum shall also be defined. Due to the severe characteristics, the survivability of warships model test in a basin must be tested with a Joint North Sea Wave Project (JONSWAP) wave spectrum. As an example, the transient flooding and survivability test has been chosen as the most representative, which will be explained in more detail in the next paragraphs.

Fig. 8. Parametric rolling test



Warship naval architects admit that the naval ship survivability is one of the most attractive and important aspects in the preliminary phases of the naval project. Survivability is the enhanced ability of a ship to survive even in damaged conditions. Therefore, for new designs, the applicable stability and buoyancy standards must be integrated with the operational requirements. As it mentioned before, righting arms after damage curves are used to determine the adequacy of the ship´s stability.

With the intention to get a good correlation between scale model and real ship, the following aspects shall be correctly defined:

- Definition of the compartments of the ship. Ships are provided with watertight subdivision to halt the flooding of water after damage and limit the spread of flooding. Increase the subdivision increases the ability to remain afloat.

- Definition of the permeability of each compartment.
- Design a good ventilation system of the model in order to avoid residual air chambers that could cause invalid results.

The model should be subjected to a long-crested irregular seaway as mentioned in the previous section (JONSWAP Spectrum) and should be free to drift and placed in beam seas with damage hole facing the oncoming waves. In 1968-1969 an extensive wave measurement program, known as the JONSWAP was carried out along a line extending over 100 miles into the North Sea from Sylt Island. From the analysis of the measurements, a spectral formulation of wind-generated seas with fetch limitation was found. The following definition of a Mean JONSWAP wave spectrum is recommended by the 15th International Towing Tank Conference (ITTC) in 1978 for fetch limited situation.

$$S(w) = \frac{172{,}8 \cdot H_{1/3}^{2}}{T_l^4} \cdot w^{-5} \cdot exp\left\{\frac{-691{,}2}{T_l^4} \cdot w^{-4}\right\} \cdot A \cdot \gamma^{B} \qquad (3)$$

$$T_l = 3{,}861 \cdot \sqrt{H_{1/3}} \qquad (4)$$

$$A = 0{,}658 \qquad (5)$$

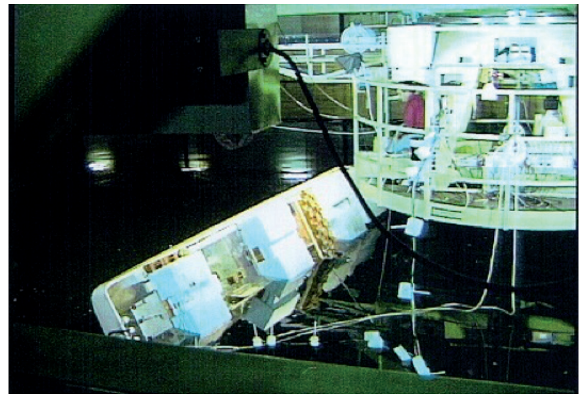
$$\gamma = 3{,}3 \quad \textit{(peakedness factor)} \qquad (6)$$

$$B = exp\left\{-\left(\frac{\frac{w}{w_p} - 1}{\sigma\sqrt{2}}\right)^2\right\} \qquad (7)$$

$$\sigma = \begin{Bmatrix} 0{,}07 & w < w_p \\ 0{,}09 & w > w_p \end{Bmatrix} \qquad (8)$$

$$w_p = \frac{2\pi}{T_p} \qquad (9)$$

Fig. 9. Damage stability test at CEHIPAR (2006)



Transient Flooding Test

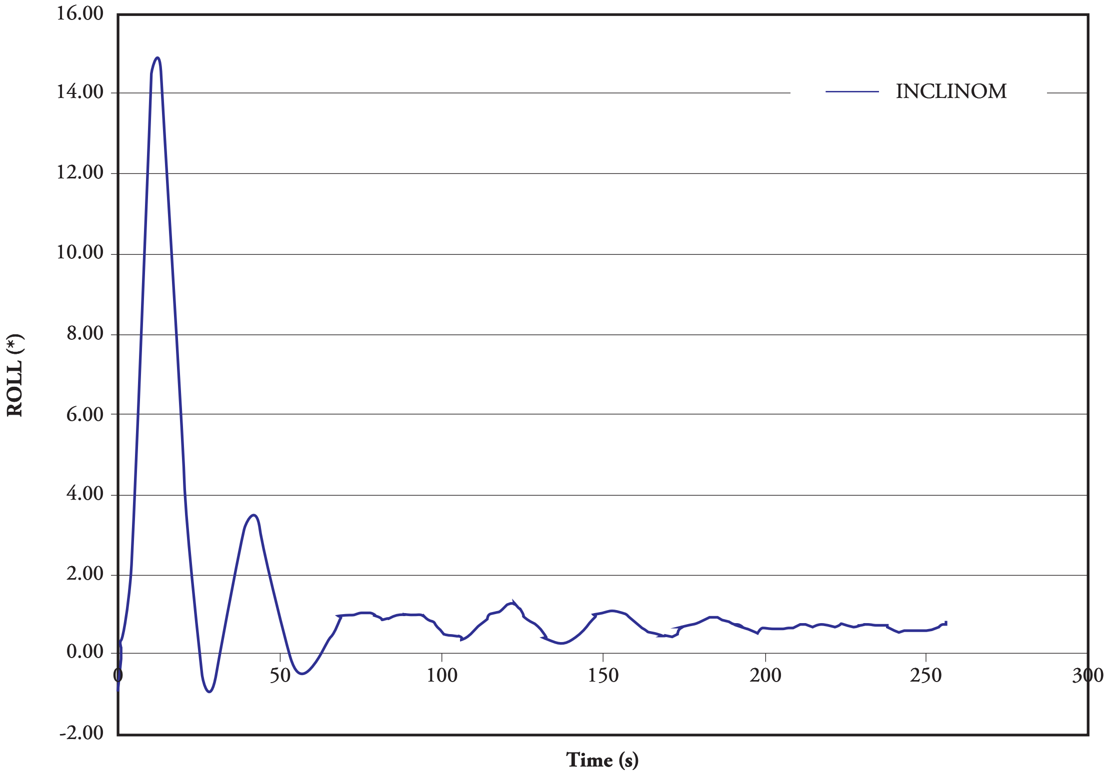
After a collision produced by another ship or an explosion produced by an enemy weapon, a sudden ingress of water could happen, inducing a fast increase of heeling moment, at least, in the damaged lateral tanks, this generates a large roll motion of the vessel. If the heel is enough to permit additional flooding, the heeling moment may exceed the residual restoring moment, which results in the capsizing of the vessel.

For ship motion simulation with sudden water ingress and waves, Cummins is the most appropriated to simulate the phenomenon:

$$\sum_{j=1}^{h}\left\{(M_{i,j}+A_{i,j})\ddot{x}_j(t) + \int_0^\infty B_{i,j}(\tau)x_j(t-\tau)\,d\tau + C_{i,j}x_j(t)\right\} = X_i(t) \qquad (10)$$

Weather conditions are important factors in a survival condition after damage. The proper method to test a scale model is based on beam seas with the damage facing the wave direction. Damage extension provides *damage categories (A, B or C) specified in ANEP-77*, residual freeboard and metacentric heights, which are the main parameters with influence in the ingress of water and the ship roll response. This test allows simulating the hydrodynamic behavior of the future ship in the event of damages in her hull. It is very important in

Fig. 10. Transient flooding test dynamic response (Riola and Valle, 2001)



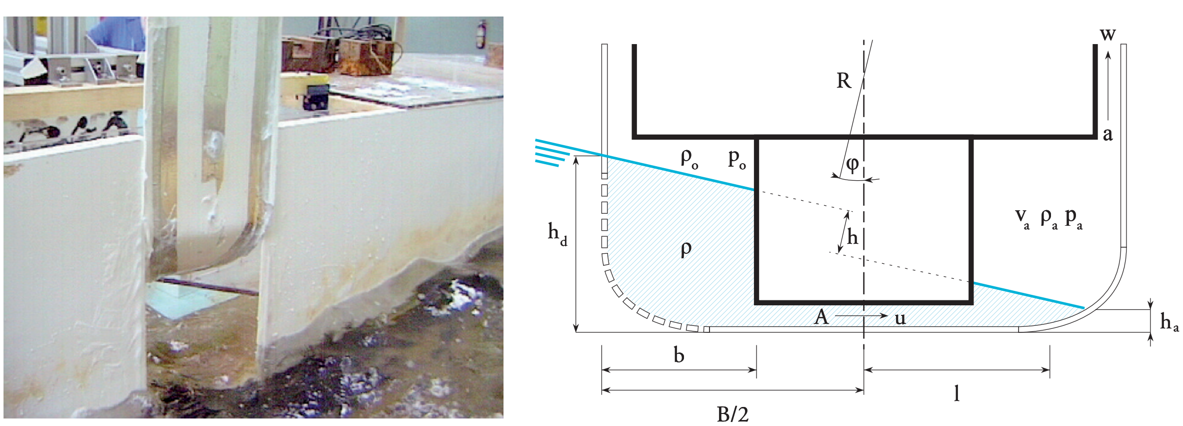
warships because they operate under hostile threats during their missions.

SICP System on F-110 Frigates Class

SICP is the Spanish acronym for Integrated Control Platform System. The main mission of the SICP is to provide up-to-date, reliable and well-structured information to SICP operators with the ultimate goal of reducing staff members dedicated to monitoring and controlling the platform, as well as to increase access to coherent and complete information on the status of the platform to the ship's command personnel.

Thanks to the design of the SICP, its operators are always fully aware of the state of the subsystems of the platform. All of these capabilities make the

Fig. 11. Survivability test and scheme of the results (Riola, 2001)



implementation and use of the SICP increase the on board safety of the ship. The SICP increases the predictive maintenance capacity by controlling and monitoring a large number of platform elements. Every parameter related with the stability tests made to the model shall be included in the SICP system in order to help in the controllability and maneuverability of the ship.

Conclusions

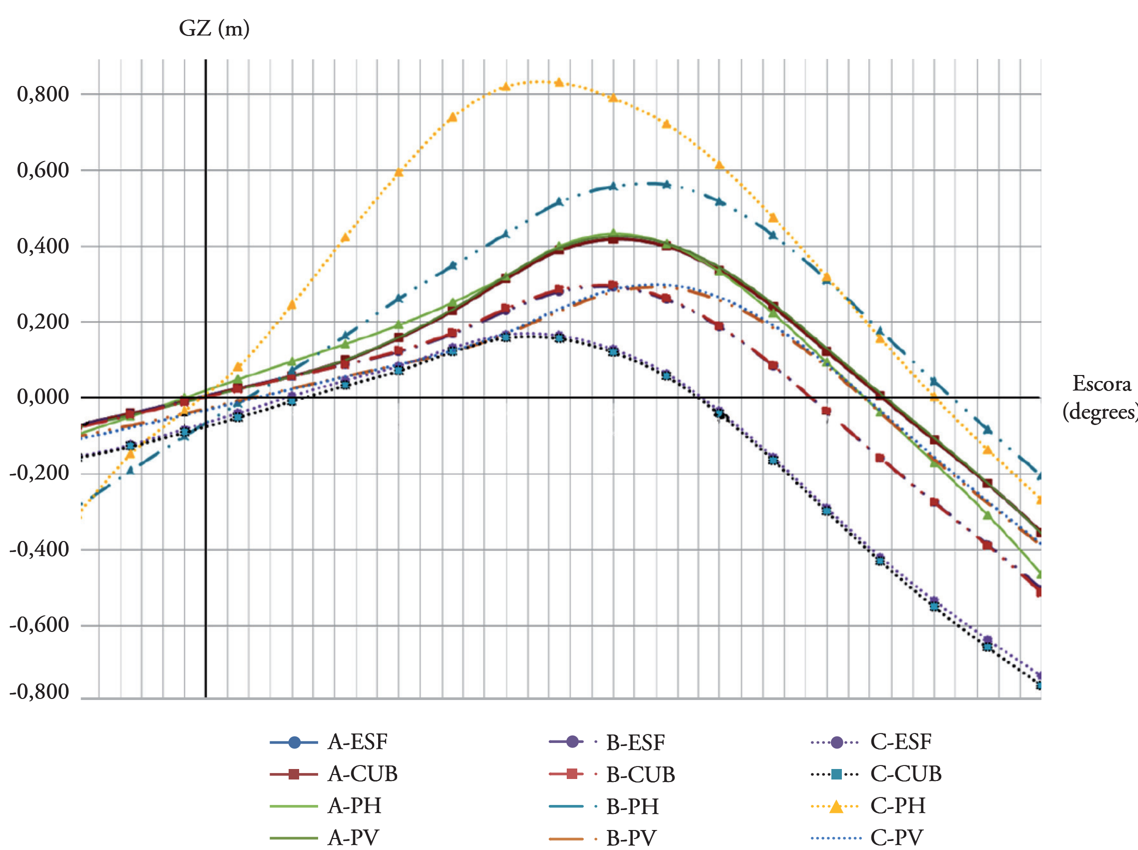
- The ANEP-77 has become the criterion of stability in damage that most closely resembles the standards of the navy in the 21st century, as it has been reflected throughout the paper.

- We have proposed an extensive explanation of the ANEP-77 stability after the damage criteria. There are many areas where military vessels could improve safety standards, although not necessarily to be regarded as less secure than the civil vessels. However, there are major difficulties in implementing all the rules of the Classification Societies in the naval field, especially to establish a priority mission and capacity combat against security. It is remarkable to distinguish the importance of the new ANEP-77 rules about dynamic ship phenomena, especially in damage tests.

- For the effective application of the ANEP-77, it is necessary to clearly define the extent of the damage that reflects the potential damage caused by hostile acts, the damage location, degree of vulnerability, hull and superstructure protection, systems redundancy, materials, the post-damage ship capability and the philosophy for recovery from the damaged state.

- Hydrodynamics Studies on damage safety aim to make F-110 frigates safer on an ongoing basis, in particular, there are many outstanding

Fig. 12. GZ comparison damages simulation for a 6.000 tons frigate (Riola, de la Puente and Gómez, 2016)



descriptions, formulas, and technical procedures on this stability paper that shows factors that can be used to develop damage scenarios for collision, grounding, and attack accidents. Damage safety assessment is not only required in the design phase but can also be applied in the operation phase that should guarantee high rapid response and useful information to the decision makers in emergencies.

- The F-110 frigate class represents a critical program into the Spanish Navy strategic goals. Before initiating the execution phase, model basin test shall be carried out to improve the capabilities of the ship. As we are actually checking at CEHIPAR, dynamic stability tests are the most critical. Damage survivability tests are a fundamental database for the future frigate behavior in operations. The data obtained from the basin tests have an enormous value for future behavior of the SICP response for the comfort of the crew in normal sailing conditions and specially, during the fast response under emergency situations.

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Calculations of the Hydrodynamic Characteristics of a Ducted Propeller Operating in Oblique Flow

Cálculos de las características hidrodinámicas de una hélice con ductos que funcionan en flujo oblicuo

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Sohrab Majdfar [2]
Hamid Forouzan [3]

Abstract

The purpose of this paper is to calculate the hydrodynamic performance of a ducted propeller (hereafter Duct_P) at oblique flows. The numerical code based on the solution of the Reynolds-averaged Navier–Stokes equations (RANSE) applies to the Kaplan propeller with 19A duct. The shear-stress transport (SST)-k-ω turbulence model is used for the present results. Open-water hydrodynamic results are compared with experimental data showing a relatively acceptable agreement. Two oblique flow angles selected to analyze in this paper are 10 and 20 degrees. Numerical results of the pressure distribution and hydrodynamic performance are presented and discussed.

Key words: Ducted propeller, Hydrodynamics forces, Oblique flow.

Resumen

Este trabajo tiene como objetivo calcular el rendimiento hidrodinámico de la hélice canalizada (en lo sucesivo Duct_P) en flujos oblicuos. El código numérico basado en la solución de las ecuaciones de Navier-Stokes promedio de Reynolds (RANSE) se aplica a la hélice Kaplan con conducto 19A. Para los resultados actuales se utiliza el modelo de turbulencia de transporte de esfuerzo cortante (SST) -k-ω. Los resultados hidrodinámicos de aguas abiertas se comparan con datos experimentales que muestran un acuerdo relativamente aceptable. Dos ángulos de flujo oblicuo seleccionados para analizar en este documento son 10 y 20 grados. Se presentan y discuten los resultados numéricos de la distribución de presión y el rendimiento hidrodinámico.

Palabras claves: hélice acodada, fuerzas hidrodinámicas, flujo oblicuo.

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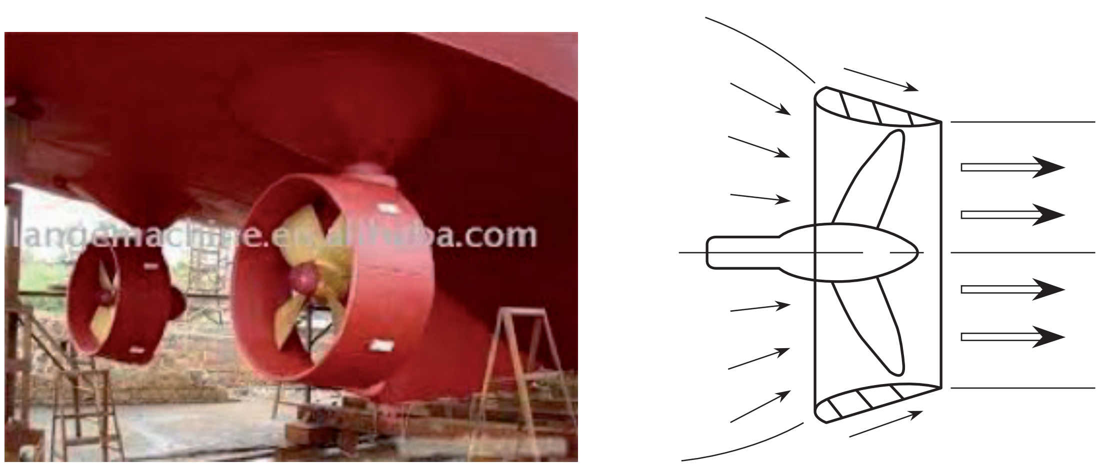
Introduction

Different types of the marine vessels are widely equipped with ducted propellers (Duct_Ps). Thrust is generated by propellers and ducts which are lifting bodies. The duct surrounds the propeller with a small slope angle. A Duct_P used on the back of the ship and also vectors that flow into the duct and the propeller are shown in Fig. 1. To give more efficiency, it is recommended using Duct_P in ships such as tugs and trawlers (a type of fishing vessel) that work in heavy conditions. Ducts produce thrust augmentation especially in heavy conditions. Generally speaking, it is said that in extreme conditions, the duct may generate 50% of the total thrust. Therefore, it is necessary to focus on the Duct_P to understand that the duct and propeller generate all forces and moments.

(Ghassemi et al.) have carried out the numerical method on the many types of propellers (contra-rotating propeller, podded draive, surface piercing propeller and ducted propeller). Many researchers have conducted various experimental and numerical approaches on Duct_Ps. *(Haimov et al. 2010)* carried out the prediction calculation method using the RANSE code to calculate the open water behavior of the Duct_P. (Kerwin et al. 1987) have used a combination of BEM to model the duct and a vortex lattice method (VLM) for the propeller. The most popular choice in Duct_P numerical studies has been the RANSE method coupled with an isotropic turbulence model like the SST k-ω model, i.e. employed by *(Menter 1994)*.

(Pangusión 2005) has developed the design of a Duct_P and model tests of a fishing research vessel. *(Falco 1983)* conducted a study about the analysis of the performance of Duct_P in axisymmetric flows. A RANS-based analysis tool for Duct_P systems in open water conditions was presented. *(Zondervan et al. 2006)* carried out a study on the flow analysis, design and model testing of Duct_P. Using a vortex lattice and finite volume methods, *(Gu & Kinnas 2003*) modeled the flow around a Duct_P. *(Broglia et al. 2013)* analyzed different propeller models and their effect on maneuvering prediction. *(Bhattacharyya et al. 2015)* conducted a study on the hydrodynamic characteristics of open and Duct_Ps by transitional flow modeling. *(Bosschers et al. 2015)* were the scholars who conducted the study in open water conditions and they applied a combination of the RANS and BEM to study the Duct_Ps. (*Dubbioso et al. 2013, 2014)* analyzed the performance of a four blade propeller INSEAN E779A model in oblique flow using CFD code in two load conditions and various oblique angles. *(Yao 2015)* researched the hydrodynamic performance of a marine propeller in oblique flow. *(A. Vega and D.L Martinez 2015)* used computational fluid dynamics to conduct a bollard pull test for a double propeller tugboat. They simulated a bollard pull test for a specific

Fig. 1. Illustrative of the Duct_P



a) DP behind a ship

b) Flow field into the Duct_P

tugboat and evaluated the results with the real test results to which it was subjected after construction.

In this study, the performance of a rotating Duct_P set at two oblique angles (10 and 20 degrees) with respect to the inflow is researched by means of an approach based on the RANSE numerical solution. This propeller type may help to improve the maneuvering of the ship. The selected propeller is the four bladed Kaplan type with 19A duct and the experimental data was obtained from *(Carlton 2013)*.

Methodology

In this paper, the propeller's rotational velocity of the propeller is imposed bymodeled using aa moving reference frame (MRF) applied to the inner region of the domain because of the high speed and accuracy of computing and simulating. The MRF is a relatively simple, strong, and efficient, CFD modeling method to simulate rotating machines. Given that the fluid flow becomes stable and transient after times a period of time and using MRF is often meaningful significant in this kind of flows, this frame was applied. In the case event of unsteady flows and when MRF is being used, the CFD codes like such as ANSYS CFX and Fluent may solve the unsteady flow. In this situation, it is necessary to add unsteady terms to all the governing applicable transport equations. The finite volume method (FVM) is used to discretize the governing applicable incompressible Navier-Stokes equations, the finite volume method (FVM) is used while in the hybrid SST-Kω turbulence model is chosen for the case of the numerical treatment of turbulence. The SST-Kω model, introduced by Menter (1994), is more accurate and reliable for a wider class types of flows since it combines the robust and precise formulation of the k-ω model in the near-wall region with the free stream independence of the k-ε model in the far field.

Continuity Equation

Continuity of Flow, as one of the key principles used in the analysis of uniform flow, is the result of the fact that mass is always conserved in fluid systems without taking into consideration the pipeline complexity or direction of flow. Euler proposed the following basic law of fluid:

$$\frac{\partial \rho}{\partial t} + \nabla . (\rho . U) = 0 \tag{1}$$

And if fluid density is constant it will be as follows:

$$\nabla . U = 0 \tag{2}$$

The equation is regardless of time for stable currents. So $\partial \rho / \partial \rho = 0$ and continuity equation is as follows:

$$\nabla . \rho U = 0 \tag{3}$$

Momentum Conservation Equation

According to Newton's second law, the change rate of momentum of a particle and the resulting fluid forces acting on the particle are equal. So momentum conservation equation, in general, is as follows:

$$\rho \frac{DU}{Dt} = f_s + f_b \tag{4}$$

where f_s and f_b are surface forces and volume forces, respectively.

Here the volume forces are equal to gravity, as well as the surface forces acting on fluid caused by tension viscosity (shear stress) and the fluid pressure. So the 4th equation is expressed as follows:

$$\rho \frac{Du_i}{Dt} = \frac{\partial \tau_{ij}}{\partial x_i} + \rho G_i \tag{5}$$

So that τ_{ij} includes the vertical and shear stresses. If $i = j$, the stress will be normal stress and in other cases the stress will be shear stress.

Temporal Discretization

In cases where fluid flow is transient, the applicable equations must be discretized in both space and time by implicit and explicit time integration methods. In order to control volumes that do not deform in time, the general conservative approximation of the transient term for the nth time step is:

$$\frac{\partial}{\partial t}\oint_{v}\rho\varphi dV \approx V\,\frac{(\rho\varphi)^{n+\frac{1}{2}}-(\rho\varphi)^{n-\frac{1}{2}}}{\Delta t} \qquad (6)$$

Where values at the start and end of the time step are assigned as the superscripts *n+½* and *n-½*, respectively, φ is a scalar quantity, ρ is viscosity, *n+1/2* value at the next time level, *n-1/2* value at the previous time level, *V* is control volume.

Numerical Implementation and Results

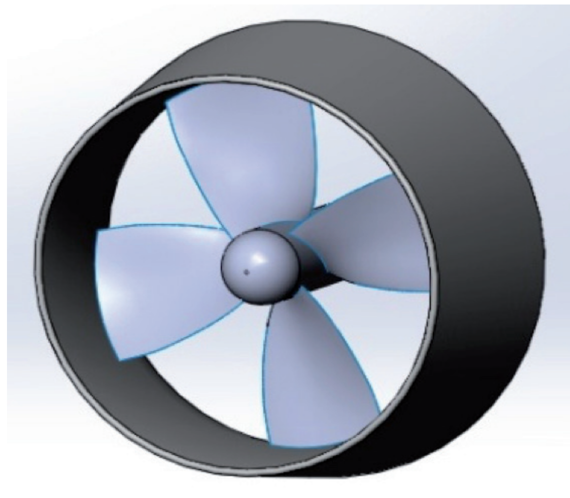
Since has a higher efficiency than a propeller with a normal blade outline when operating in a duct, it is the most common propeller for Duct_Ps. Having a large chord at the tip is one of the physical characteristics of a Kaplan type propeller. The Kaplan propeller with a P/D ratio of 0.8 is used in the entire analysis of this paper. Geometric modeling of a Kaplan propeller was done with Propcad and Solidworks software. Kaplan geometric data and Duct is shown in Table 1.

Due to the favorable hydrodynamic characteristics, 19A is the most common accelerator type of duct and when it is used with the Ka propeller series it will be more useful in the designing of Duct_Ps. The ducts' length is equal to half of the propellers' diameter (L_p=0.5DP) and the distance between the propellers' tip and the inner surface of the duct is equal to one percent of the propellers' diameter (gap=1%D_p). Fig. 2 shows the three-dimensional model of the Duct_P created in Solidworks.

Table 1. Kaplan geometric parameters and duct

Parameter	Value
Propeller Diameter	Dp=300mm
Number of blades	Z=4
Pitch ratio	P/D=0.8
Expanded Area Ratio	EAR=0.70
Duct length	L=0.5DP
Duct type	19A

Fig. 2. Assembled duct and propeller



Mesh Generation and Boundary Conditions

ICEM software is applied to generate unstructured mesh in Duct_P and domains. The generated mesh size grows outwards at a 1.2 ratio. Boundary conditions include inlet, outlet, rotating domain, open water, propeller and duct. Fig. 3 shows the meshes near the propeller and the duct. Due to the complex geometry of the propeller and its gap with the duct, this surface is first divided into seven separate surfaces and a structured quadrilateral surface grid is generated for each one. The average size of the mesh elements on the propellers' surface at its finest generated mesh is 0.005Dp. Then, this surface mesh is extruded in a wall-normal direction with a transition ratio of 1.1 (for finest generated mesh), an initial layer thickness of 2.5×10^{-5}m (corresponding to $Y^{+} = 1$) and a layer numbers of n = 50 that results in a streamlined structured hexahedral mesh volume in near-field flow. In the first step, 4 million meshes were used for meshing the model; then, using smaller meshes, 5, 5.5, 6, 6.2 and 6.5 million-cell models were tested and the results were compared at an advanced ratio of 0.4. Comparison of the results shows that the minimum number of cells for this model is 6 million. Fig. 4 shows the mesh convergence of the thrust coefficient. The computational domain consists of an internal rotating cylinder containing Duct_P and an external stationary cylinder with a radius of 1.5D. The inlet uniform boundary condition is located at 3D upstream of the propellers' plane and the constant pressure condition is imposed at 6.5D downstream.

Fig. 3. Mesh cells on the propeller and duct

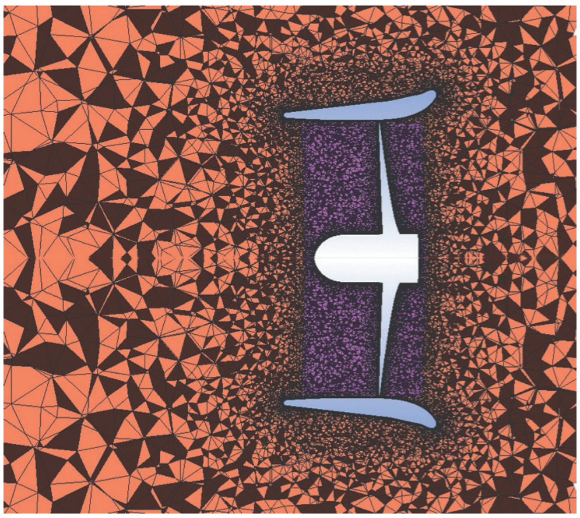
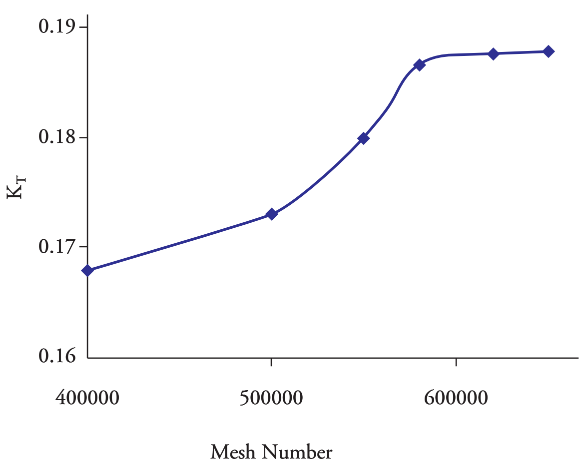


Fig. 4. Mesh convergence of the thrust coefficient (J=0.4)



Solver Setting and Validation

A tri-linear interpolation of the pressure and velocity is applied to solve the RANS equations. A high-resolution method is applied in order to solve velocity-pressure coupling and advection scheme in continuity and momentum equations. Also, a second order backward Euler for transient scheme in continuity and momentum equations and upwind method to solve advection turbulence kinetic energy k and specific dissipation rate ω are applied. The SST turbulence model is selected in most of the articles, because of its popularity due to its higher accuracy. Total duration of time is set to 10 seconds and the time steps are selected based on the propellers' rotating speed for each run.

Hydrodynamic performance of Duct_P is defined as follows:

Advance ratio:

$$J = \frac{V_A}{nD} \tag{7}$$

Thrust coefficient (duct and propeller and total):

$$K_{T_d} = \frac{T_d}{\rho n^2 D^4}, K_{T_p} = \frac{T_p}{\rho n^2 D^4}, K_T = \frac{T}{\rho n^2 D^4} \tag{8}$$

Torque coefficient:

$$K_Q = \frac{Q}{\rho n^2 D^5} \tag{9}$$

Efficiency:

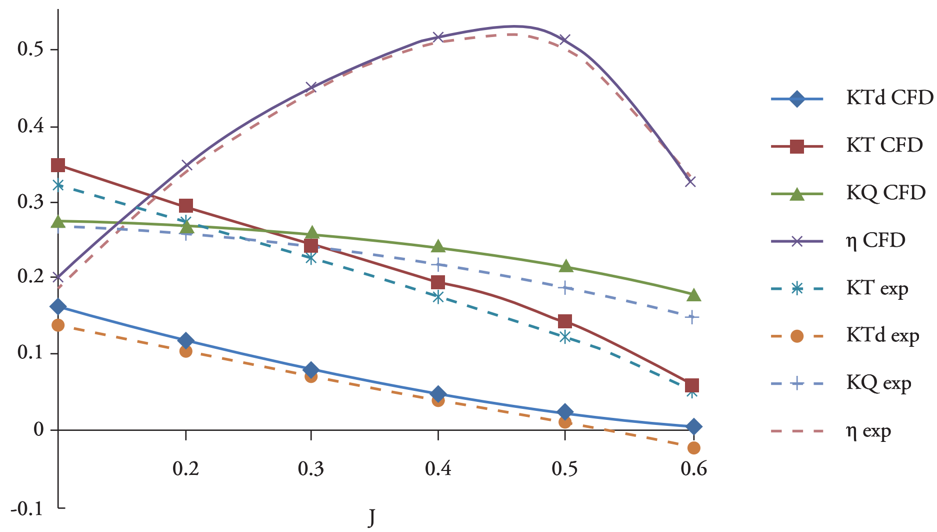
$$\eta = \frac{K_T}{K_Q} \cdot \frac{J}{2\pi} \tag{10}$$

where V_A is advanced velocity, n is revolution per second (RPS), D is propellers' diameter in meters, T is the total thrust, T_p and T_d are the thrust of the propeller and duct, ρ is water density and Q is total torque. Comparison of hydrodynamic performance of the Duct_P in open flow is shown in Fig. 5. The relative error is about 8% at heavy loaded condition (J=0.1) but at the design condition (J=0.45) the error is less than 3%.

Results and Discussion in Oblique Flow

The propeller has been tested for two different advance ratios (J=0.3 and 0.5), covering a relatively

Fig. 5. Comparison of the numerical and experimental hydrodynamics performance of Duct_P

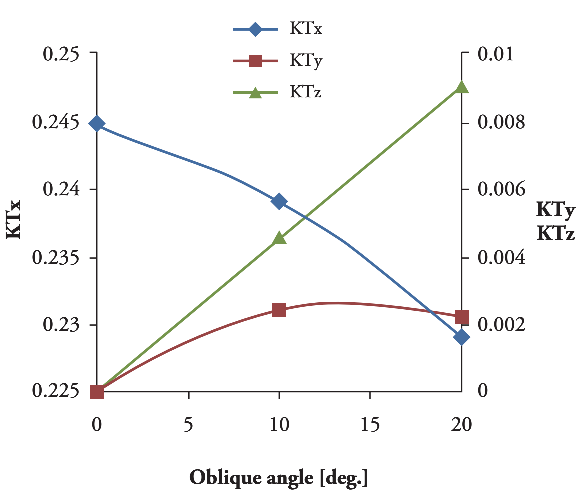


broad set of oblique angles (up to 20). In this numerical simulation, the advance velocity has been kept fixed at a value of 1.5 m/s (V_A=1.5 m/s) and a rotational velocity of the propeller varied for each condition. The total time duration set to 5s and time steps varied for each advance ratio. Time steps were selected according to the rotational velocity that the propeller would rotate 5o in each time step. For *J*=0.3 time step was 0.005s and for *J*=0.5 time step was 0.0083s. The focus of the numerical results is on forces and moments produced by the Duct_P and the distribution of pressure on the blade and duct.

Fig.s 6 and 7 show the coefficients of the forces (*KTx*, *KTy*, *KTz*) and the coefficients of the moments (*KQx*, *KQy*, *KQz*) against oblique angles of 0º, 10º and 20º degrees at *J*=0.3 and *J*=0.5. The x-component of force (means thrust coefficient *KTx*) and moment (means torque coefficient *KQ*x) are important and larger than others. When the oblique angle increases, thrust decreases and torque changes are different. Other components increase when the oblique angle increases.

The hydrodynamic characteristics of Duct_P at oblique angles of 0º, 10º and 20º are shown in Fig.

Fig. 6. Coefficients of forces and moments of the Duct_P at a 0.3 advance ratio



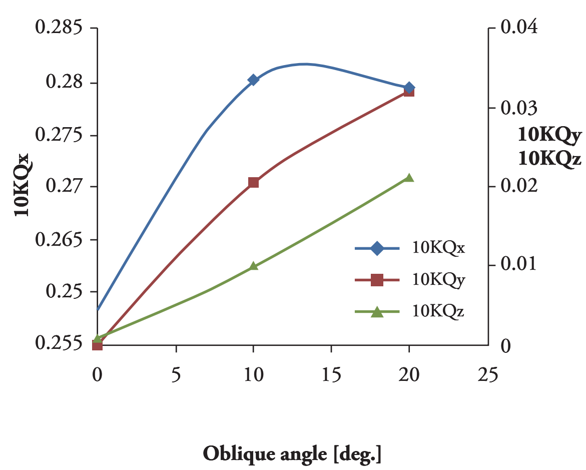
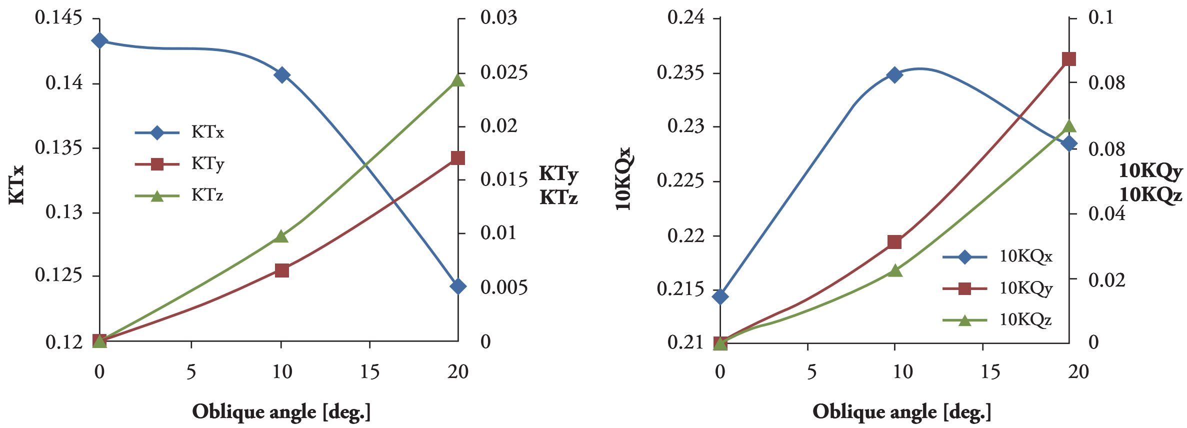


Fig. 7. Coefficients of forces and moments of the Duct_P at a 0.5 advance ratio



8. The results show that torque does not change when the angels are changed but thrust and efficiency change at all advance coefficients. Fig. 9 shows pressure field on the rear of Duct_P at an advance coefficient of 0.3 for both angles of 10 and 20 degrees. Quantitative comparisons of pressure distribution coefficients

$$C_p = P / 0.5\rho V_R^2 \quad \text{where,} \quad V_R^2 = V_A^2 + (2\pi rn)^2$$

on the propeller blade and duct are presented in Figs. 10 and 11. The results obtained at two advance ratios (J=0.3 and 0.5), oblique angles of 10 and 20 degrees are shown in Fig. 10. Lower pressure is obtained at the rear of the blade and also on the inner side of the duct. Pressure is almost constant on the outer surface of the duct, while it is low on the inner surface from the leading edge of the duct to x/C=0.55 (middle length of chord) because in this part, the pressure can decrease alot due to the rear side of the propeller. Cavitation happens at the most time in this part. For this reason, special materials should be used to prevent erosion.

Fig. 8. Hydrodynamic characteristic of Duct_P at various oblique angles

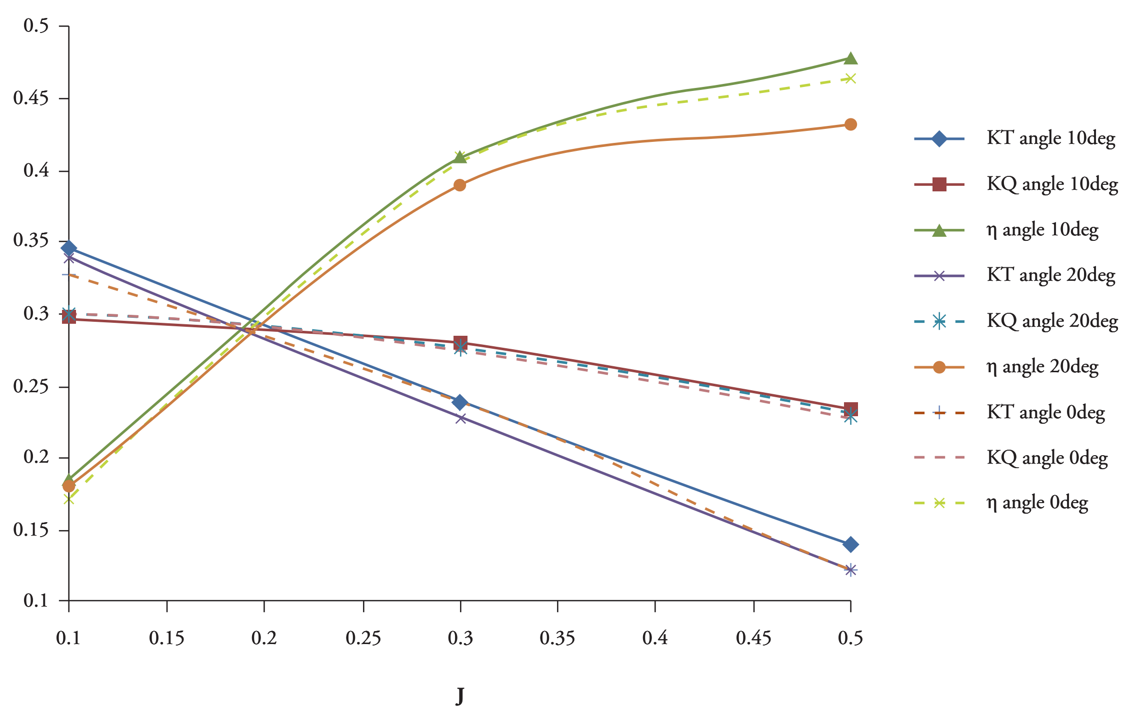
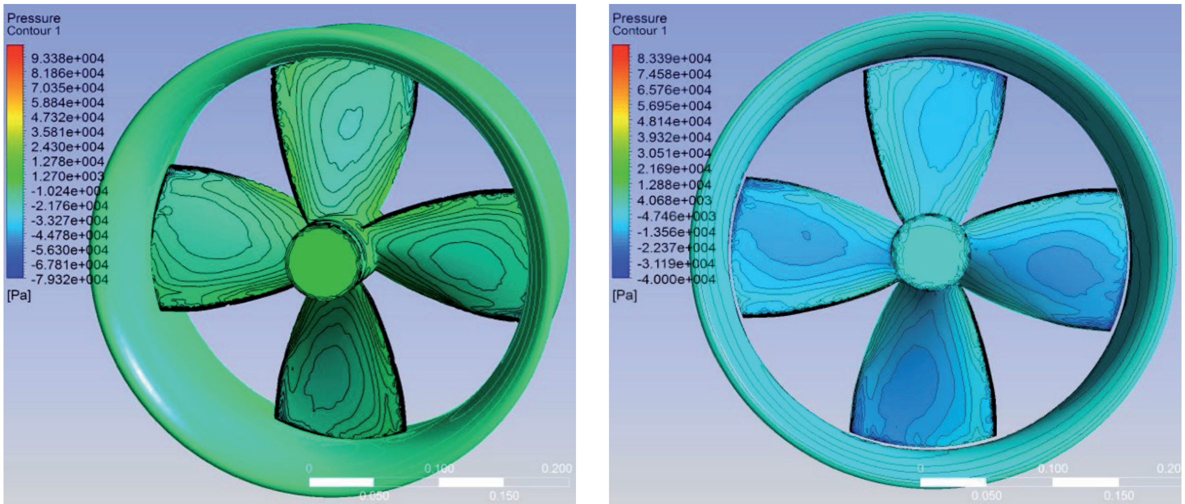


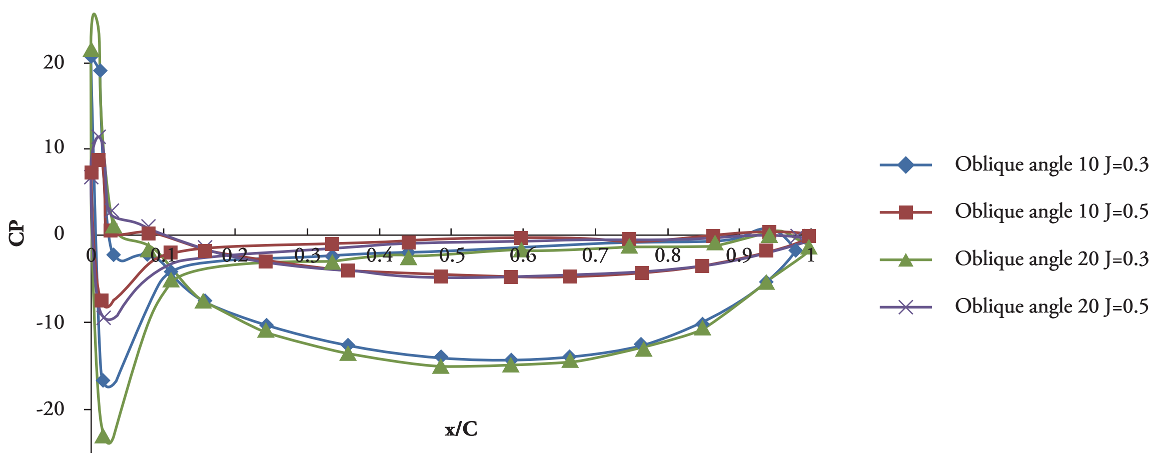
Fig. 9. Pressure field on rear of Duct_P at J=0.3



a) angle of 20º

b) angle of 10º

Fig. 10. Pressure coefficient at blade radius section r/R=0.5



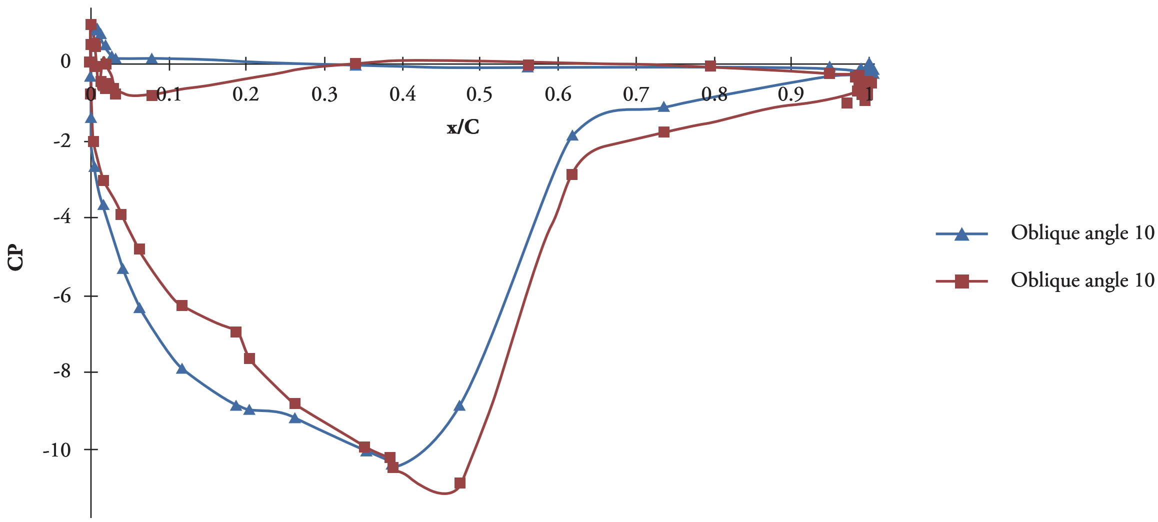
Conclusions

In this article, the Kaplan propeller with duct 19A is analyzed at two advance ratios of 0.3 and 0.5 by the numerical method in open water and oblique flow conditions (10 and 20 degrees). The following results can be drawn:

- Hydrodynamic performance of Duct_P is compared with the experimental data and shows good correlation at high advance coefficient but some discrepancy at low advance coefficient.
- Pressure distributions are obtained on the propeller blade and duct. Low pressure and high pressure are at the rear side of the blade and duct.
- Hydrodynamic performances of the Duct_P are compared at oblique angles (10 and 20 degrees). When oblique angle increases torque does not change, while efficiency significantly changes especially at high advance coefficients.

Greater understanding of the flow at the propeller downstream and the other oblique angles is required. This is a research area that the authors intend to pursue in more detail in the future.

Fig. 11. Pressure distribution on duct profile at J=0.3



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Onshore Reception Facilities for ballast water

Instalaciones de Recepción en tierra para agua de lastre

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Abstract

This paper completes an exploration analysis of onshore ballast water treatment alternatives at major ports. The authors had presented results for option (1) ballast water treatment onshore installed in two iron ore ports in 2012 applying the discrete events simulation model. Now, two more options are presented: (2) mobile and (3) desalination reception facilities. The previous simulation model developed called TRANSBALLAST, was adapted to consider these two new alternatives. This model was applied to the same ports presented in 2012 and this evaluation also includes one more port with 50 million tons annually (Mta) of iron ore transport capacity. The results uncovered that for (2) there is an increase of 1.90 days on the average waiting time of ships that moored at Port 1. In (3), the average waiting time and berth occupation rates were observed to remain the same presented in (1). One of the major differences between the systems consists in catching sea water to increase the desalination plant operational capacity. Among those three onshore ballast water treatment alternatives, (2) does not impact port terminals infrastructure. Additionally, option (2) could be offered to ports users as a ballast water treatment service and ship-owners might not need any onboard ballast water treatment system. (3) Might be feasible to ports regions without enough water supplies solving two issues: transfer of invasive species from ballast water and water recycling.

Key words: Port, Ballast Water Desalination, Barge, Onshore Water Treatment, Mobile, Shipping, Brazil, Fresh Water.

Resumen

Este ensayo realiza un análisis exploratorio de alternativas de tratamiento de agua de lastre en tierra en puertos principales. Los autores habían presentado resultados para la opción (1) del tratamiento en tierra de agua de lastre instalado en dos puertos de minerales de hierro en 2012 aplicando el modelo de simulación de eventos discretos. Ahora, se presentan dos opciones adicionales: (2) móvil e (3) instalaciones de recepción de desalinización. El modelo de simulación anterior desarrollado que se denominó TRANSBALLAST, fue adaptado para considerar estas dos nuevas alternativas. Este modelo fue aplicado a los mismos puertos presentados en 2012 y esta evaluación también incluye un puerto adicional de 50 millones de toneladas al año (Mta) de capacidad de transporte de minerales de hierro. Los resultados concluyeron que para (2) hay un aumento de 1.90 días de promedio de tiempo de espera de naves que atracaron en el Puerto 1. En (3), el tiempo de espera promedio y las tasas de ocupación de atraque fueron observadas para mantenerse igual que las presentadas en (1). Una de las principales diferencias entre los sistemas consiste en atrapar agua de mar para aumentar la capacidad operacional de la planta de desalinización. Entre esas tres alternativas de tratamiento de agua de lastre, (2) no tiene un impacto en la infraestructura de los terminales de puertos. Adicionalmente, la opción (2) puede ser ofrecida a usuarios de puertos como un servicio de tratamiento de agua de lastre y los propietarios de naves podrían no necesitar ningún sistema de tratamiento de agua de lastre a bordo. (3) Podría ser viable en regiones portuarias sin suficientes suministros de agua resolviendo dos problemas: la transferencia de especies invasivas del agua de lastre y reciclaje de agua.

Palabras claves: Puerto, Agua de Lastre, Desalinización, Barcaza, Tratamiento de Agua en Tierra, Móvil, Navieras, Brasil, Agua Dulce.

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Introduction

Ballast water impact has been widely discussed *(Carlton and Geller, 1993) (Gollasch, 2006) (Minton, et al, 2005) (Hallegraeff, 1992) (David and Gollasch, 2014).* Since 2004, the International Maritime Organization (IMO) has attempted implementing the International Convention for the Control and Management of Ships Ballast Water and Sediments – ICBWS IMO, 2004.

During the last 9 years a great effort has been dedicated to ratify ICBWS *(Cohen and Dobbs, 2015) (David and Gollasch, 2014)*; however, there is a lack of member countries' that agrees on this subject. Today, 44 countries representing a combined tonnage of 32.86% of the world merchant fleet have ratified the convention ICBWS (IMO). Seeking to meet ICBWS requirements, a number of systems of Ballast Water Treatment (BWT) have been developed over the last years *(Jing et al, 2010).* There are 53 certified treatment systems that could be installed on ships (*Cohen and Dobbs, 2015).* Moreover, *(King et al, 2012)* shows that there is a potential $50 to $70 billion market for BWT.

The United States is imposing a criteria that is 100 to 1,000 times more restrictive than IMO *(Pereira and Brinati, 2012).* Thus, with a worrying scenario for ship-owners and environmental managers, ratified BWT systems are being tested since 2011 *(Dobroski, et al, 2011) (Albert et al. 2013)* and none of them meet the criteria established by California and Michigan. On the other hand, tests on the equipment for the treatment of ballast water discharges need transparence and better science to avoid bad choices by shipowners *(Cohen, 2015).*

The lack of solution onboard ships increases the need for new studies into Ballast Water Treatment Onshore (BTWO) . Hence, this study presents an extension to the exploration study into BWTO at major ports. *(Pereira and Brinati, 2012)* presented results for option (1) Ballast Water Treatment Onshore installed in 3 Brazilian iron ore ports. Now, two new options are presented: (2) Mobile and (3) Desalination Receptions Facilities.

Option (2) has been approached in several scientific studies with no practical application *(David and Gollasch, 2014) (McMullin et al, 2008) (Liu et al., 2011).* This treatment alternative was first reported in the Australian Quarantine and Inspection Service (AQIS) in 1993, and presented at the National Research Council in a book entitled "Stemming the tide: controlling introductions of nonindigenous species by ships' ballast water". It can treat BW of ships that do not have treatment installations on board, or also catch ballast water from ships and transport it to a coastal treatment unit. *(McMullin et al, 2008)* evaluated the usage of barges to capture ballast water from ships. *(Pereira and Brinati, 2008)* explained that this kind of transport might also be done by deactivated tanker ships adapted to the operation. *(Gollasch et al, 2007)* suggest that this option is only applicable in special circumstances as in ports with berth limitation, similar to oil exportation ports where one or two ships can moor on the opposite side and operate at the same time.

The use of mobile reception facilities can be applied to solve onboard ballast water issues and assembling onboard barges or trucks. These mobile reception facilities may be brought alongside the vessels. However, ships such as container vessels, continuously need to ballast/deballast in port areas according to the cargo handling.

On the other hand, *(Pereira, 2012)* demonstrates that (2) solves a discussion related to delay in operation and area disposal for assembly treatment tanks at port terminals. However, impacts in port operations are less meaningful *(Pereira and Brinati, 2012).* Since not all the treatment is performed at the berths area, this system presents greater flexibility regarding conventional BWTO.

The BWT at the port is also feasible *(Donner, 2010) (Jing et al, 2010) (Pereira and Brinati, 2012) (Minkelis, 2012).* Operational viability of this system for ballast water treatment was presented by *(Pereira and Brinati, 2012).* Valdez port treats around 10 million cubic meters per year (Mm^3/year) and Scarpa Flow has reception and treatment stations that are able to perform 16 Mm^3/year, including ballast oil from the water. Ballast water of ships is then collected and treated onshore *(Gollasch et al, 2007)*.

None of these analyses considered the installation of a Ballast Water Desalination Plant (BWDP). *(Donner, 2010)* presented this system as likely to solve environmental issues generated by ballast water. The great advantage of desalination stations is the possibility to install a conversion plant far from the water caption point. Thus, if a port has any area restriction to receive tanking, there is no concern about this operation. For instance, in the Arab Emirates there are desalination plants in the coast that convert the water and conveys it to distances longer than 30 km *(Ahmed, 2001)*. Desalination plants are installed around the world as a means to provide fresh water to regions with limited drinking water availability. These plants are installed in the Arab Emirates, Israel, Australia, United States, Mexico and Brazil, at Fernando de Noronha Island. *(Donner, 2010)* explains that building a desalination plant with sufficient capacity would not be a concern considering that great cruise ships currently operating already hold 3,000 m^3/day desalination plants.

There are two desalination alternatives: thermal and reverse osmosis. These two alternatives proved to be very efficient to eliminate exotic species. The thermal treatment rises the ballast water temperature to above 45°C since present organisms die at this level. Reverse osmosis occurs with water going through a series of high pressure membranes. This process is essential to disaggregate the organisms in the ballast water because of the membranes denseness *(Castaing, 2010)*. Chemical substances that eliminate organisms might be added during pre and post treatment.

Ballast water treatment systems on board ships might use filtration. The filter thickness at desalination is lower than on board ships. The desalination plant requires filters between 0.1m and 0.2 m in thickness *(Çakmakce et al, 2008)* while on board ships may vary from 10 to 50 µm *(David and Gollasch, 2014)* due to possible clogging. This only reinforces that desalination is more efficient at separating microorganisms present in ballast water compared to onboard systems. There are no residue treatment issues; however, its efficiency is guaranteed when applied. Hence, desalination is used as an on land alternative and it is not necessary to implement other BWTO systems.

Adaptations to the simulation computational model where considered for (2); ballast water treatment was only used at the backshore. Hence, all the ships that arrive at the port area may have to wait for treatment before entering in it. Ballast water reception and conversion was implemented for (3) together with sea water caption whenever the berth was not occupied by a ship. This implementation is necessary to guarantee higher desalination plant occupation rate.

We used the same input data presented in *(Pereira and Brinati, 2012)*. Simulations were made at The Port of Tubarão (Port 1), which handles approximately 90 million tons annually (Mta) and receives ships from 60,000 to 400,000 Deadweight Tonnage (DWT) unloading around 25 Mm^3/y. The Port of Sepetiba handles approximately 50 Mta (forecast for 2015 for port 2) and 25 Mta on port 3, respectively.

Results demonstrated that for option (2) there is an increase of 1.90 days in the average waiting time for ships that moored in Port 1 considering an optimized fleet to attend the demand. This effect is a result of ships retention on backshore for BWT even when berths are free for operation. Even in these conditions, all projected transport demand was attended. These results confirm the premise *(Gollasch et al, 2007)* that treatment on land may generate delays on port operations when the mobile alternative is applied with a few shuttle fleets. It was observed that for desalination BWT the average waiting time and berth occupation rate remained at the same level presented in *(Pereira and Brinati, 2012)*. The major difference between the systems is sea water caption to expand desalination plant operational capacity. The captured volume from ships and from sea ratio was about 37%. This effect is explained by the ships maneuver time and the non-occupied berths.

Thus, this study completes the evaluation of onshore ballast water treatment alternatives discussed in the literature. The focus on iron ore terminals is explained by the high ballast water volumes that is transported by these ships. We have made the analysis considering the same volumes proposed by a previous study (*Pereira and Brinati, 2012)*. However, those terminals may have changed transport volumes. Once again, our final conclusion is that onshore treatment is a possible option for those terminals to reduce the impact of organisms present in ballast water. On the other hand, these treatment options could offer port users a ballast water treatment service to be paid by ship-owners, who would not need to install any ballast water treatment system onboard.

Ports Localization

The Port of Tubarão (Port 1) (a) is located in Vitória, ES, and has 3 mooring berths. Berth 1 is divided in 1 (North) and 2 (South) and may receive 2 ships simultaneously. It is limited to ships of up to 200,000 DWT. Berth 2 serves ships with capacities greater than 380,000 DWT. The Port of Sepetiba (Port 2 under construction and 3) is located in Rio de Janeiro, RJ, and is a complex port that deals with different types of ships and loads. The iron ore is handled by two companies in two different terminals. Two terminals were selected: (b) a port under construction, designed to operate with two berths in the first phase in 2015 following a ramp up in cargo handling; and (c) a port that operates with one berth and receives ships of up to 180,000 DWT.

Methodology

New Computational Implementation

A discrete event simulation model was developed and called TRANSBALLAST, version 2. This model was originally presented in (Pereira and Brinati, 2012) to treat ballast water in port (1). From this model, two new models were developed to allow simulating two new onshore treatment conditions: (2) mobile treatment for the anchorage area and (3) port treatment using a desalination station.

Mobile reception facilities

The mobile system consists of treating ballast water in backshore while other ships wait to moor in port. This system is a fleet of shuttle tankers with an onboard treatment system (oceanic barges or simple hull ships) that picks up and treats ballast water from ships in backshore.

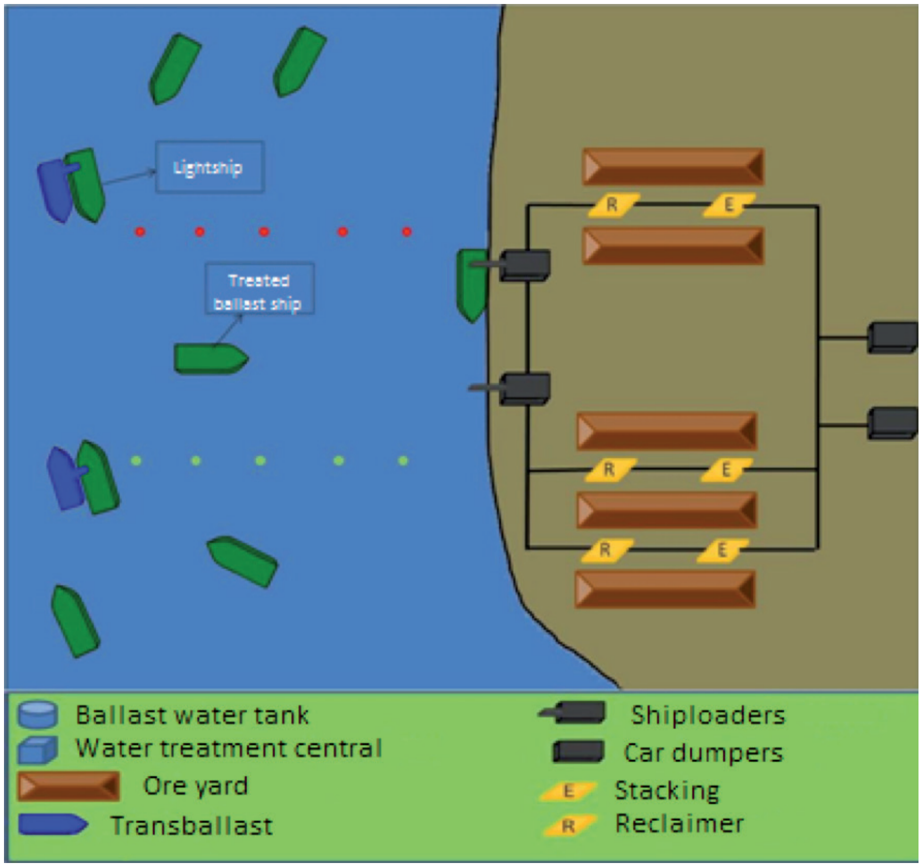
Ships might only moor at port berths after the ballast water transfer has been conducted. Ships usually discharge part of their ballast water during navigation, throughout the access channel and when arriving at the mooring berth, affecting the ports' surrounding environment. This system aims to prevent this water from being discharged at the adjacent port. This alternative treatment is shown in Fig. 1.

The model firstly verifies the number of queuing ships waiting to access the port. Then, it verifies the availability of deballast and water treatment units. If at the moment when a ship arrives to the channel there is a treatment ship available, it is immediately assigned to deal with the ship that is queuing, respecting the First In First Out – FIFO concept. Otherwise, ships wait in queue until a treatment ship is available.

After the ballast ship is mooring, the same logic of transfer system is applied, regarding the ballast water collection, transfer and treatment processes as shown in *(Pereira and Brinati, 2012)*. Hence, when a ship moors, there is a pre-operation time to connect short manifolds ruled by a triangular probability distribution. Available treatment types for the mobile system is the same presented for the in land system.

Before starting the treatment, the model verifies the amount of ballast in ships and, during the transfer, verifies the total volume on board and removes the volume from the ship every 1,000 m^3. When the volume on board is zero, the deballast ship unmoors and continues treating the residual volume inside its own tank. After finishing the

Fig. 1. Mobile reception facilities scheme for an iron ore terminal



residual water treatment, the system verifies if there is any ship in queue and assigns a new operation.

Considering that the ship waiting time at the port area should be reduced to the minimum level, this type of alternative may induce higher times and block ship loading. Before starting the transfer, the model verifies the amount of ballast on board the ship, and during the transfer, it reduces the total volume removed from the ship every 1,000 m^3.

When the on board volume is zero, a shuttle tanker unmoors and continues treating the residual volume inside its own tank. After the end of the residual water treatment, the system verifies if there is any ship accessing the channel or any berth and assigns it to a new operation.

Desalination reception facilities

This system works together with the ballast water treatment in port; however, there is no treatment option to eliminate exotic species. It also generates fresh water. The model calculates the stations' occupation according to the ballast water volume received every day and the desalination rate (m^3/h). If the tanks' volume is not enough to feed the desalination station with ballast water, sea water is used as shown in Fig. 2 and Fig. 3.

Ballast water captured from tanks processes for feeding a desalination station should guarantee that the plant fully operates within the time available. The model assumes that the station works at 99% occupation rate including ballast and seawater, whenever necessary.

Through statistics from the simulation model, we might be able to determine the frequency and time period when sea water caption is necessary to guarantee the total usage of the desalination station.

Fig. 2. Conceptual representation of desalination ballast water treatment (This alternative evaluates only ballast water treatment in a desalination unit without evaluating the operation on land at port)

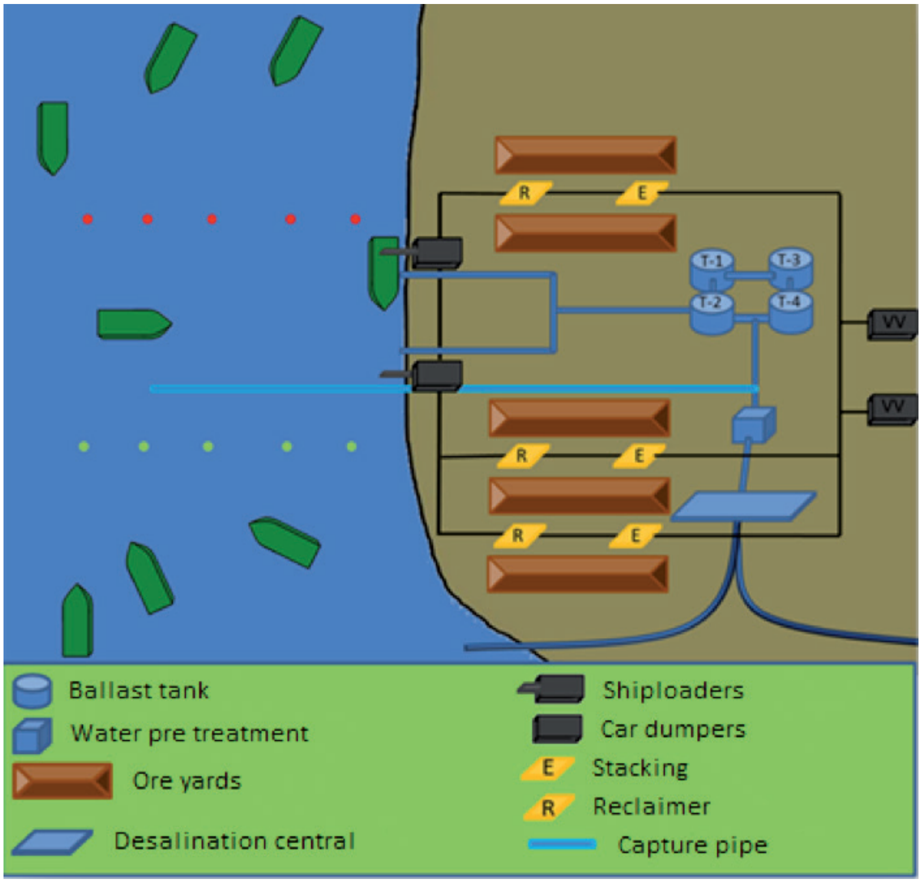
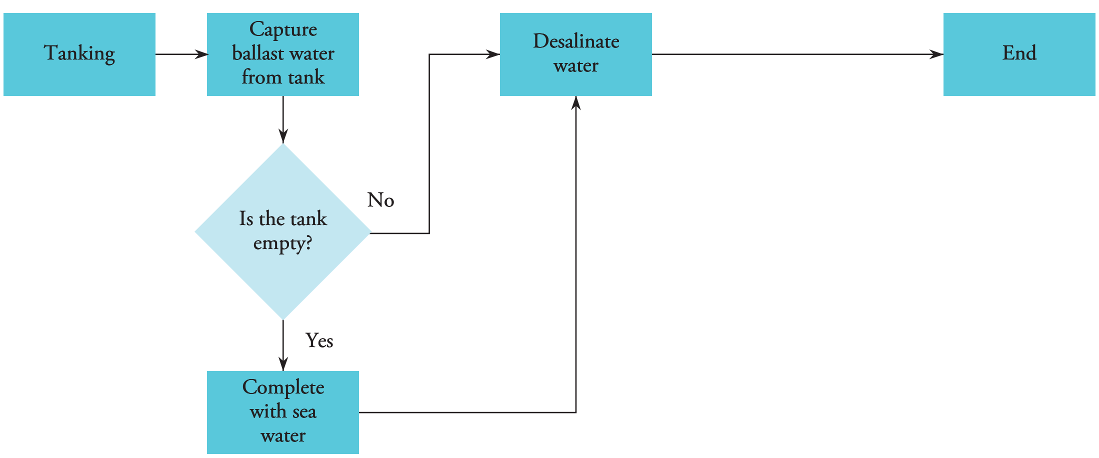


Fig. 3. Schematic representation of desalination station functioning



General considerations to simulation

The scenarios developed for simulations considered two treatment alternatives: (a) shuttle tankers and (b) desalination stations. Specific parameters were adopted for each alternative. General premises for these simulations were already presented in *(Pereira and Brinati, 2012)*. Only the specific premises will be presented for the simulations of those two alternatives as follows.

Shuttle tankers

The capacity of the shuttle tankers is associated to two parameters: (a) capacity of ballast waters on board the largest ship that moors at the terminal; and (b) ballast water treatment rate of shuttle tankers.

The proposed model determines the average occupation level of shuttle tankers. It is assumed that after the main ship finishes transferring ballast water to the shuttle tanker, the ship is free to moor at the berth and the shuttle tanker is ready for the next operation. The shuttle tanker should finish treating all the ballast water inside the tank. After completing a waiting time that may vary from 0 to 24 hours according to a triangular distribution that aims at representing the effect of stops on possible preventive maintenance, supply and crew changes, the shuttle tanker returns to operation.

In this evaluation, Very Large Ore Carrier (VLOC) ships might also be considered to moor at Port 1, being served by the system proposed.

Premises for simulation
To simulate this alternative, the principal premises are: (1) number of shuttle tankers; (2) treatment capacity rate of shuttle tankers (m^3/h); (3) navigation time from the backshore to the port (h); and (4) loading rates of ships at berths (t/h).

Expected results
By imputing this data into the simulator, we may obtain the following outcomes: (a) average queuing time of ships in backshore; (b) average number of queuing ships in backshore; (c) ship stay in backshore (days); (d) fleet of shuttle tankers and their respective capacities (m^3); and (e) occupation rate of shuttle tankers (%).

By possessing these real outputs, the results of the model might be evaluated as well as the impact of the solution proposed for each port shown in *(Pereira and Brinati, 2012).*

Desalination Station

One of the principles of the desalination station is holding up a continuous flow of water supply for the conversion of treated fresh water. It is important to highlight that there are stops during the operation of ships other than vacancies due to the lack of ships. To minimize the effects, salt water may be stored in tanks to be later destined to the desalination station in a constant outflow (m^3/h).

Premises:
To simulate this alternative, the following premises are included: (a) outflow of tanks to the desalination plant (m^3/h); (b) average desalination rate (m^3/h); and (c) percentage of fresh water generated by the desalination process (m^3/h).

Results expected:
Other than the results presented by *(Pereira and Brinati, 2012)*, adding the following is expected: (1) flow entry of desalination station (m^3/h); (2) frequency of stops of tank pumping; and (3) extracted sea water volume per year (m^3). To validate this system, the same results presented in *(Pereira and Brinati, 2012)* are used.

Simulations Results

Results generated by the simulation model may be compared to the results presented in *(Pereira and Brinati, 2012)*. Considering that the validation scenario adopted was the same, we consider that the comparison of those results impacts each one of the simulated alternatives.

Mobile reception facilities results

Input parameters
The input of parameters to the simulation model are the number of shuttle tankers, corresponding to the discharged ballast water storing capacity (m^3) and treatment rate (m^3/h). Different parameters sets were considered. The average time assumed for the shuttle tanker mooring operation to the ship and coupling of short hoses to collect ballast water is 2 hours, according to the information collected from shuttle tankers operation within FPSOs.

Base scenario results

Table 1 presents the results for each of the ports using alternative (2). It should be pointed out that these results correspond to better tested configurations.

The results presented for this alternative consider the following. Port 1: ideal configuration for the system is obtained with 2 shuttle tankers, each of them with a treatment rate of 5,000 m^3/h. It can be noted that with the adoption of this treatment system, there is an increase of 1.90 days in ship staying time if compared to the results presented in *(Pereira and Brinati, 2012)*. This increase is intuitive as long as the ship may arrive at the backshore and there is a berth available; however, it stays on hold to perform ballast water transference. It impacts directly on the ship queuing average time. As expected, the berth occupation rate remains constant since the port continues to serve the same number of ships. The effect is focused on the availability of the arrival of ships to the berths. It might be observed that the shuttle tankers occupation rate is 87%. There is still a 13% gap in the system that might absorb the demand increase for the terminal, as it considers that established premises are conservative. Obviously, it may be noted that this rate has been impacted by time

Table 1. Results of simulation for mobile reception base scenario

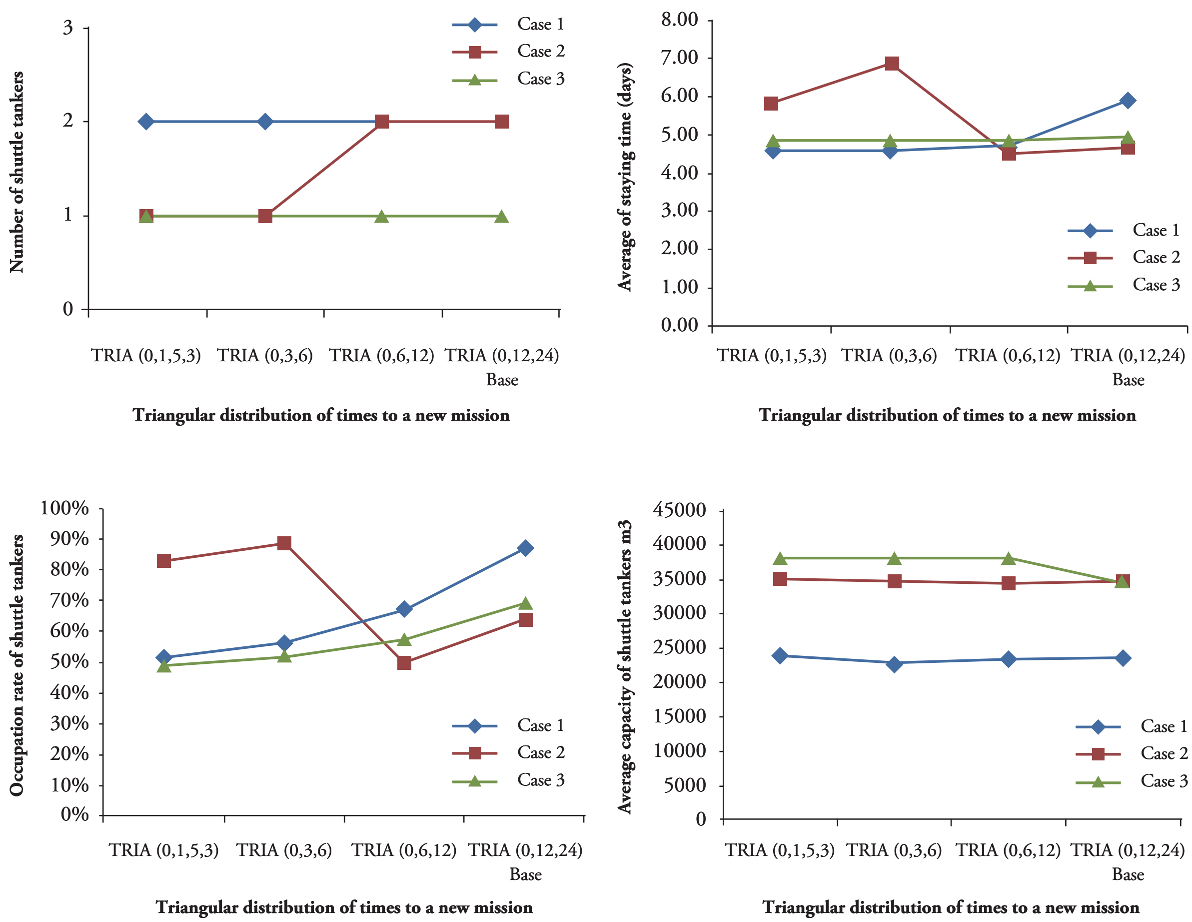
Description	Port 1 5,000 m^3/h 2 shuttle tankers	Port 2 3,000 m^3/h 2 shuttle tankers	Port 3 2,000 m^3/h 1 shuttle tanks
Expected transportation demand (t)	90,000,000	50,000,000	25,000,000
Attended transportation demand (t)	89,964,000	49,981,000	24,987,000
Expected ballast volume (m^3)	27,000,000	15,000,000	7,500,000
Discharged ballast volume (m^3)	26,995,000	14,998,000	7,496,000
Average ship Stay (days)	5.93	4.71	4.97
Berth occupation			
Berth 1 (%)	61%	0%	71%
Berth 2 (%)	85%	75%	0%
Berth 3 (%)	76%	72%	0%
Ships attended by class			
Number of Handymax ships	54	0	0
Number of Panamax ships	116	128	11
Number of Small Cape ships	0	0	0
Number of Capesize ships	270	225	151
Number of Large Cape ships	112	25	0
Number of Very Large Cape ships	47	0	0
Number of VLCC ships	0	0	0
Average ships queue on backshore			
Average number of queuing ships	2.84	2.08	0.30
Average time of ships in queue (day)	4.54	3.24	3.11
Occupation of shuttle tanker ship			
Ship 1	87%	64%	69%
Ship 2	87%	64%	0%
Maximum storing capacity required (m^3)			
Ship 1	23,544	34,740	34,663
Ship 2	23,020	34,495	0

distribution to new imputed missions in the model. Another important subject is that in relation to the high treatment rate (5,000 m^3/h), the maximum occupied capacity of tanks remained at 23,500 m^3. Two Handymax ships would be enough to deal with all the ballast water volume discharged at the terminal. There are treatment systems in the market with this capacity that could be installed onboard shuttle tankers.

Port 2: The composition suggested for the system was 2 shuttle tankers with a treatment rate of 3,000 m^3/h. The average stay was 4.71 days. The occupation rate of shuttle tankers is 64%. Hence, as the 3,000 m^3/h treatment rate is less than that in Case 1, an opposite effect occurs in which the maximum occupied capacity of the tanks was 34,700 m^3. The rate increases due to the need to store more water where treatment is occuring. For the 5,000-m^3/h treatment rate, the capacity of the tank is 16,000 m^3. For this system, two Handymax ships are needed to deal with all the ballast water volume discharged at the terminal, in relation to the time for a new ship operation, varying from 0 to 24 hours.

Port 3: The composition suggested for this system was 1 shuttle tanker ship with a 2,000 m^3/h treatment rate. The average stay was 4.97 days. The increase of the treatment rate reduced the stay time in 0.10 days for 3,000 m^3/h and 5,000 m^3/h; however, it does not mean there is a significant benefit to system. The increase in the average time in queue is analogous to the increase of ship stay. It might be observed that the shuttle tankers occupation rate is 69%. The tanks maximum occupied capacity is 34,600 m^3. For this system, one Handymax ship is necessary to deal with all the ballast water discharged at the terminal.

Fig. 4. Variation effect in new shuttle tanker mission time (TRIA is a triangular distribution of times for a new mission; values were changed to evaluate the impact on the fleet usage, as well as on the system service capacity)



An important consideration about this system is that there is no type of interference in the existing port system, i.e., all the operation occurs outside the port area.

However, the time proposed for a new ship operation is a parameter that has a direct influence in determining the shuttle tanker fleet size. Hence, sensitivity analysis was performed considering this time variation, as shown in Fig. 4.

A reduction in time for a new mission affects the number of shuttle tankers for Port 2. It might be verified that time after time, TRIA (0, 3, 6) reduces one ship. This analysis is important because there is a great uncertainty about operational times for ballast water treatment. The reference used was oil operation and there is a significant difference between those two operations.

Impact of operation of VLOC ship in case 1

We tried to evaluate the VLOC ships operations impact on the system proposed (5,000 m^3/h treatment rate and 2 shuttle tankers). Results

Table 2. Sensitivity analysis results with the inclusion of VLOC ship

Description	Alt, 3	Alt, 3,A	Alt, 3,B	Alt, 3,C
Expected transportation demand (t)	90,000,000	90,000,000	90,000,000	90,000,000
Attended transportation demand (t)	89,964,000	89,969,000	89,963,246	89,960,000
Expected ballast volume (m^3)	27,000,000	27,000,000	27,000,000	27,000,000
Discharged ballast volume (m^3)	26,996,000	26,998,000	26,994,849	26,996,000
Average ship Stay (days)	5.93	5.75	5.72	5.88
Berth occupation				
Berth 1 (%)	61%	61%	61%	61%
Berth 2 (%)	85%	83%	75%	70%
Berth 3 (%)	76%	73%	82%	87%
Ships attended by class				
Number of Handymax ships	54	54	54	54
Number of Panamax ships	116	116	116	116
Number of Small Cape ships	0	0	0	0
Number of Capesize ships	270	270	242	214
Number of Large Cape ships	112	45	45	45
Number of Very Large Cape ships	47	79	79	79
Number of VLCC ships	0	12	24	36
Average ships queue on backshore				
Average number of queuing ships	2.84	2.70	2.68	2.91
Average time of ships in queue (day)	4.54	4.33	4.26	4.38
Occupation of shuttle tanker ship				
Ship 1	87%	85%	84%	83%
Ship 2	87%	85%	84%	83%
Maximum storing capacity required (m^3)				
Ship 1	23,544	78.750	67.500	62.680
Ship 2	23,020	77.340	67.500	62.680

are divided in the following order: Alternative 1: without VLOC ships inclusion; Alternative 3,A: VLOC ships inclusion, transporting 5% of demand: Alternative 3,B: VLOC ships inclusion, transporting 10% of demand; Alternative 3,C: VLOC ships inclusion, transporting 15% of demand. The premise assumed that part of the transported demand by capesize ships will be transferred to VLOC ships, Table 2.

VLOC ship inclusion in the system impacts the average waiting time of ships regarding the Base Scenario. In alternatives 3,A and 3,B, a small reduction is verified at the stay time. This result was expected after the reduction of the number of ships at the terminal. However, for alternative 3,C, there is an increase due to a larger number of VLOC ships. Regarding port impacts, the berth occupation rates were not changed *(Pereira and Brinati, 2012)*. A decrease in theshuttle tankers occupation rate was observed when the number of VLOC ships increases at the terminal. In this

Table 3. Results of simulation for desalination station reception base scenario

Port-Treatment and capacity rates at tanking	Port 1 5,000 m³/h 40,000 m³	Port 2 3,000 m³/h 20,000 m³	Port 3 2,000 m³/h 20,000 m³
Expected transportation demand (t)	90,000,000	50,000,000	25,000,000
Attended transportation demand (t)	89,978,000	49,991,000	24,989,000
Expected ballast volume (m³)	27,000,000	15,000,000	7,500,000
Discharged ballast volume (m³)	26,993,000	14,997,000	7,496,000
Average ship staying time (days)	4.04	3.75	3.95
Berth occupation			
Berth 1 (%)	61%	75%	70%
Berth 2 (%)	85%	72%	0%
Berth 3 (%)	75%	0%	0%
Ships attended by class			
Number of Handymax ships	54	0	0
Number of Panamax ships	116	128	11
Number of Small Cape ships	0	0	0
Number of Capesize ships	270	225	151
Number of Large Cape ships	112	25	0
Number of Very Large Cape ships	44	0	0
Number of VLCC ships	0	0	0
Average ships queue on backshore			
Average number of ships in queue	4.31	2.36	0.95
Average ship queuing time (day)	2.64	2.28	2.13
Average waiting time until deballast (hours/ship)	0.01	0.00	0.12
Desalination station stops			
Number of stops per year	1.691	1.323	478
Average time of each stop (hours)	1.99	2.81	10.79
Total time stopped (days/year)	140	155	215
Desalination rate m³/h	5,000	2,980	2,080
Total received in m³ by sea (year)	16,799,000	11,060,000	10,743,000
Total received in m³ by sea (day)	46,030	30,300	29,440
Total daily volume of plant in m³	119,980	71,392	49,980

case, the average capacity of tanks is 70,000 m3. In other words, 2 Panamax ships are necessary to serve the system regarding the high volume transported by these ships at an average of 120,000 m^3.

Results of desalination reception

The first simulation was called Base-Alternative, as it refers in itself to the current characteristics of ports. These results follow these criteria: a) to meet the annual transportation demand and ballast water treatment at the lowest tank storage possible, and b) to ensure that occupation rates and queues remain at the same level as the validation condition *(Pereira and Brinati, 2012)*. At the beginning of the simulation, the ballast water receiving tank was considered empty.

The results indicate that the berth occupancy rate and queue time for all ports remained at similar validation degrees. In Ports 1 and 2, there were many stops in the tank pumping system during the year because of the high rate of ballast water transfer, Table 3.

Therefore, the volume of sea water collected is more significant in these alternatives. In this sense, it is important to examine the need of adopting a combined system to capture the water and to guarantee a constant supply to the desalination system. The importance of determining the daily volume of water collected is that this is the parameter used to select the desalination unit to be assembled at a certain location. Fig. 5 presents the history of the ballast water receiving tanks behavior. A restriction was imposed on the model: the exchange of the ocean water capturing system will only be possible when the capacity of the first tank is 50%. Hence, it may be possible to notice that during approximately 2% of the time, the reception tank capacity varied between 90% and 100% of Port 1 capacity Fig. 5.

Fig. 6 shows the mean volume of water delivered to the desalination system, which is composed of the ballast water received and the ocean water captured when the reception tank is empty.

Approximately 37% of the volume received in Port 1 derives from ocean water as there are 4.63 stops per day to supply the tanks. This occurs because the average berth occupancy rate is around 74%. Observing that there are vacant periods during the annual operation, where there are no ships at the port, the system is supplied with ocean water in 37% of the total operation time. The system behavior is analogue to Ports 2 and 3. The ballast water volume received at these ports is lower as well as the berth occupancy rate. Thus, the volume of

Fig. 5. Histogram of ballast water reception tanks

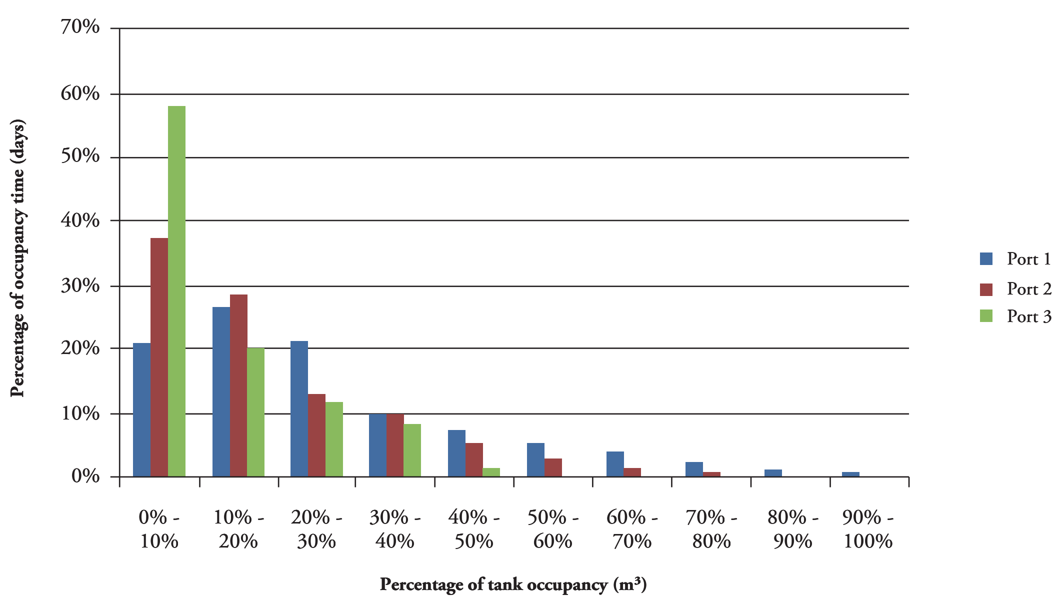
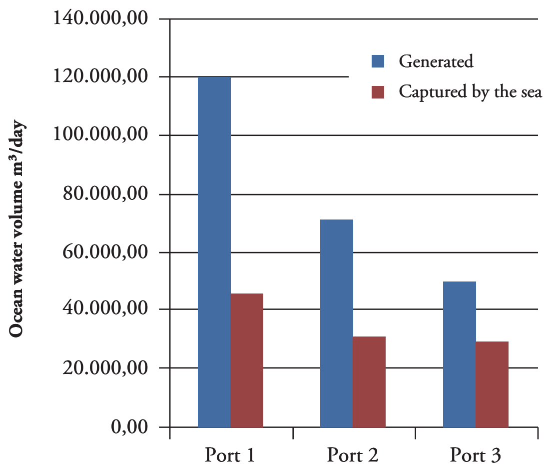


Fig. 6. Daily histogram of total water receiving tanks of ships and sea water.



ocean water collected is higher in order to supply the desalination plant.

In all the ports berth occupation and staying time was observed to remain at levels similar to those shown in *(Pereira and Brinati, 2012).* At Port 1 and 2, a number of tank pumping system stops were verified to occur during the year due the high ballast water transfer rate. The sea water volume collected is more representative in those alternatives. In this case, it is important to verify that it is highly necessary to adopt combined systems for water capturing to guarantee constant supply to the desalination system. The importance of determining the daily water volume collected is that this is the parameter used to select a desalination unit to be assembled at a specific location.

Evaluation of the terminal surrounding areas for installing desalination stations

Based on the areas available at the port surroundings, we tried to evaluate if the areas available are sufficient for a desalination system installation that uses reverse osmosis technology. Several studies were consulted providing data of the area occupied by this type of installation that uses the technology proposed for this alternative. Table 4 presents the major characteristics of desalination stations, with special interest in establishing a correlation between station capacities versus occupied area.

Stations that had treatment capacity similar to those defined by the simulation model, were selected. Google Earth was used to verify areas available in those ports surroundings. It is worth noting that there is not a precise correlation between the occupied area versus the desalination station production capacity.

It was observed that all the ports had enough areas to install both reception tanks as well as desalination stations. Note that the use of any alternative energy source that would demand additional areas in the ports surroundings was not considered. Another important point is that there is a significant variation between the areas occupied by desalination stations. Hence, the examples cited are only for reference purposes. It will be necessary to develop a specific project.

Table 4. Major characteristics of some desalination stations

Station	Location	Capacity m^3/year	Capacity m^3/day	Area m^2	Source
Ashkelon	Israel	116,800,000	320,000	75,000	Sauvet-Goichon
Hadera	Israel	166,440,000	456,000	70,000	http://www,water-technology.net
North Obhor	Saudi Arabia	4,872,750	13,350	14,400	Sawaco Water Desalination
San Francisco	USA	5,000,000	13,699	8,093	San Francisco Bay Conservation and development commission
SOJECO	Saudi Arabia	3,650,000	10,000	22,000	Sawaco Water Desalination
Tampa Bay	USA	34,541,885	94,635	2,787	Tampa Bay Water
Victorian	Australia	200,000,000	547,945	380,000	Victorian Desalination Project
Wonthaggi	Australia	200,000,000	547,945	360,000	http://www.water-technology.net

Discussion

Mobile receptions facilities

The results for this alternative show that ballast water treatment in mobile reception unities does not impact the ship loading capacity at ports. All the ships generated during the simulation were attended. Although the average queuing time was higher in comparison to the validation scenario, those results justify themselves by the operational characteristic of the system. The effect on this alternative refers to an increase of stay time of ships in ports.

The major advantage of this system regarding the conventional method of onshore ballast water treatment *(Pereira and Brinati, 2012)* is its independence from the port. A similar system was studied by *(McMullin et al, 2008)*. Ocean going barges are simpler than ships and might have great ballast water stocking capacity. This alternative was not considered in this paper; however, the necessary stocking capacity might be confronted with the barges capacity to determine the number of barges necessary for treatment. The problem of using barges is that all of them must have on board treatment systems.

On the other hand, this system allows several treatment alternatives to be used inside the receiving vessel. This provides flexibility regarding the operation at the port. Tanker ships no longer in operation could be adapted to provide this service for ports surroundings. This solution also presents the concept of scale economy. As observed, few units would be capable of attending several ships. In terms of capacity and treatment rates, those values are verified to be at offered market system levels. As the treatment system is continuous, there is no loss of time between the reception operation and the start of on board ballast water treatment. Hence, if reception and treatment rates are compatible, downtimes for operations will be minimal.

These types of operations are known by maritime operations as transshipment or ship-to-ship. The system presented in this paper shows nothing different from what already exists in maritime transport operations. Transshipment is highly applicable in iron ore operations and oil transference in open sea.

Also, this option should be faced by ports and shuttle tankers as an opportunity to generate a new service at the ports, such as existing fresh water supply services, bunker, amongst others.

On board BWT systems already installed on ships are under the risk of being replaced due to new restrictions imposed by California *(Pereira and Brinati, 2012) (Albert et al. 2013)*. Those issues could be minimized if those systems were used only at onshore or offshore stations at ports surroundings.

Desalination reception facilities

The simulation results indicate that installing a desalination plant does not impact the ship loading capacity at ports. All ships generated by the system were attended. Stoppages in loading due to the deballast system presented times less than 1 hour per ship.

At these ports, both the berth occupation and queue time were verified to remain at degrees similar to those in the data gathered by (*Pereira and Brinati, 2012)*. Ports 1 and 2 presented many breaks in the tanks pumping system during the year because of the high rate of ballast water transference. The capture of water in the tanks and the ocean has to be combined to guarantee the constant supply of the desalination plant.

These results demonstrate the possibility of assembling a recycling system for the ballast water discharged at the ports to avoid the proliferation of exotic species and vector of diseases at these ports. From a technical stand point, there are no restrictions to this implementation as it might be installed in stages: first, the BWT system eliminates exotic species; and second, a desalination plant might be installed without affecting the port operation.

Installing a desalination plant to treat the ballast water is a rarely explored initiative *(Donner, 2010)*. Onshore ballast water treatment is focused on eliminating exotic species using filtration, UV radiation, hydro cyclone separation, biocides, and other techniques applied to on board treatment in ships and that may be combined. However, these systems do not present efficacy to eliminate 100% of the species present in the ballast water.

Among the current desalination processes, both reverse osmosis and thermal process proved to be the most efficient solutions for ballast water. In reverse osmosis, water is projected to a membrane where the separation of water and salt occurs. This process uses micro membranes up to 0.2-µm of thickness which are capable of filtering microalgae such as *(Castaing, 2010)*. After the desalination process, the water undergoes treatment for chemical and micro biotic stabilization, palatability and pH correction. The current standard recommended by IMO-D2 is <10 organisms per cubic meter greater than 50 µm *(David and Gollasch, 2014)*. The standard established by California Law does not allow organisms greater than 50 µm. For organisms between 10 and 50 µm it cannot not be more than 0.01/ml *(Dobroski, et al, 2011)*.

Desalination through distillation via multiple-effect distillation (MED), multi-stage flash distillation (MSF) and vapor compression (VC) consists in heating the water until its ebullition temperature. Among the alternatives to treat ballast water, there is the proposition of using the heat lost in the ships' propulsion to heat the ballast water. To eliminate organisms, ballast water has to be heated to temperatures varying between 35º and 80º *(Gregg et al. 2009) (Quilez-Badia et al. 2008)*, and kept heated until the organisms are eliminated. Thus, the thermal process tends to guarantee the complete elimination of organisms present in the ballast water.

Ballast water desalination may generate a new business in ports that receive high volumes of ballast water. On the verge of lack of fresh water in many parts of the world, this alternative should not be rejected to those who manage and invest in ports operations.

In the ports evaluated for this paper there are areas available for building a desalination plant. The advantage of installing a desalination plant is that it does not need to be constructed near the port, favoring highly dense ports.

Conclusions

The ballast water management alternatives presented in this article might be installed at ports. Among the three alternatives (1) *(Pereira and Brinati, 2012)*, (2) and (3) for ballast water management and treatment, option (2) was identified as the option that does not impact the port structure. However, an increase in ships stay time at the port was verified if compared to the two alternatives in land. In these simulations, this increase of time did not rule out operations at terminals and we determined a minimal number of shuttle ships to attend the transport demand. If we increase the number of shuttle ships, this time may reduce; however, these ships might present low occupation rate. Considering that iron ore ports in Brazil presents elevate high number of ship waiting in queue, this effect might be dissipated during port operations. Hence, while a ship waits, treatment is provided.

Treating ballast water in a desalination plant (3) also appears to be an alternative to be assembled at port areas. However, it is necessary to build it next to or far from the port structures to provide this treatment. As this alternative was less explored in the literature for this matter, this study opens the opportunity for new researches to be conducted and to determine its viability of eliminating exotic species, as well as an economic evaluation.

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Implementation of a methodology to design evaluation models in Technology Transfer projects

Aplicación de metodología para el diseño de modelos de evaluación de proyectos de Transferencia Tecnológica

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Abstract

This document introduces the implementation and development of a methodology for the establishment of an assessment model used by COTECMAR and the Colombian National Navy (Armada Nacional de Colombia), which allows for the valuation of different strategies or routes in technology transfer projects that are in conceptual or definition phase. This model contains different attributes that may be parametrized, according to the ponderation of the variables that represent the development of a project. In addition, the application of this model, allows for the decision-making process to be assessed quantitatively, based on the best relation between the effectiveness measures, cost and risk.

Key words: assessment models, measurement of performance, effectiveness, cost, risk, technology transfer, naval system.

Resumen

Este documento presenta la aplicación y el desarrollo de una metodología para la elaboración de un modelo de evaluación empleado por COTECMAR y la Armada Nacional de Colombia, que permita valorar diferentes estrategias o rutas en proyectos de transferencia tecnológica que se encuentren en fase de definición o conceptual. Este modelo, se compone de atributos disimiles que pueden ser parametrizables, acorde a la ponderación de las variables que representan el desarrollo de un proyecto. Además, la aplicación de este modelo permite la toma de decisiones valorada cuantitativamente, basada en la mejor relación de las medidas de efectividad, costo y riesgo.

Palabras claves: Modelo de evaluación, medida de desempeño, efectividad, costo, riesgo, transferencia tecnológica, sistema naval.

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Introduction

Designing an assessment model that allows for decision making, based on the cost-efficiency-risk relationship, is a challenge for those who evaluate alternatives that lead to the solution of a Project or an important action within an organization.

The designed model evaluates three (03) dimensions, which through their correlation, support decision-making:

- Effectiveness in the fulfillment of the objectives of the project.
- Project development cost and integrated logistic support of the naval system.
- Assessed risk from the perspectives of scope, timeline and cost.

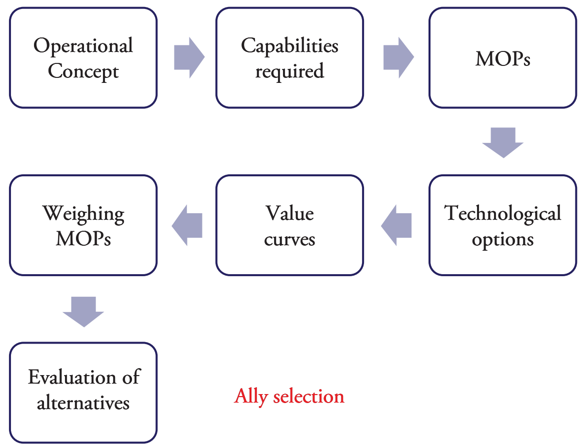
Each one of these measures is obtained through the application of an effectiveness, risk and cost model respectively. The methodology used to define these models in relation with the selection of the different alternatives for the development of the Project is described below.

Methodology to evaluate Effectiveness

Fig. 1 presents a general view of the different phases of the model, which allows to obtain an Overall Measurement Of Effectiveness (OMOE) [2], which is acquired for each selection alternative. The following premises are required for the development of the project:

- The operational includes operation, maintenance, and integrated logistic support of the system to be developed.
- The operational capacities required include the high-level functionalities which must provide the solution and capacities to develop in order to extend the life cycle.
- The Measures of Performance (MOP), are weighted values of the different capacities and functionalities to be assessed in the model.
- The technological Options, value curves and weighing of the MOPs are criteria that may be quantifiable according to their nature. These criteria are described in the application of the model.

Fig. 1. Stages in the effectiveness model

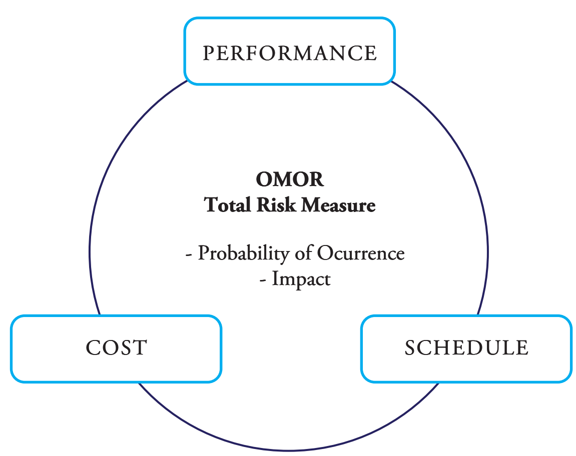


Risk Assessment Methodology

Fig. 2, presents the general outline of risk events, associated to the Overall Measurement of Risk (OMOR). The evaluation of risks associated to performance, cost, and timeline is done through the identification, analysis and priorization of adverse effects to the Project, considering their impact, and occurrence probability.

Per [3], this type of risk assessment is greatly important during the phases of exploration and conceptual design of a Project, or when considering new technologies, unique processes and new concepts.

Fig. 2. Stages of the risk model



The development methodology for this model is based on the following procedure:

- Identify potential areas of risk and events associated to each one of them.
- Assign probabilities of Occurrence (Pi) and impacts (Ci) associated to each risk event (Ei).
- Define the function of the Overall Measurement Of Risk (OMOR).

Methodology to evaluate Cost

Fig. 3 shows the general outline of the main components of cost, associated to the Overall Measurement Of Cost (OMOC). The result of this evaluation will show the equivalent value (cost) for each alternative or proposal, including specific costs and additional COTECMAR-ARC costs, associated to each one of the alternatives.

To obtain the OMOC measurement, the costs associated to the development of the system are first identified, which implies the identification of the required association: supplier, ally, or contractor, and inclusion of the required costs for the development of the project (association cost). Likewise, the input (goods) and services, personnel and indirect costs associated to participation (participation costs), required are also related.

Additionally, the costs associated to Integrated Logistic Support, where the costs required to guarantee the life cycle of the system (cost of life cycle) are also identified.

Fig. 3. Main components of the cost evaluation model

Implementation of the methodology

The following is a description of the model obtained as of the implementation of the methodology presented above.

Effectiveness Model

As of the operational concept, the first Group of experts, identifies the required capacities to achieve success in the execution of the project:

- Functional capacities of the system
- Technical capacities of the system
- Integration capacity of the system
- Capacity to manage the life cycle of the system

Each one of these categories is associates to an affinity group[1] in the assessment model. In this case four (4) groups were identified:

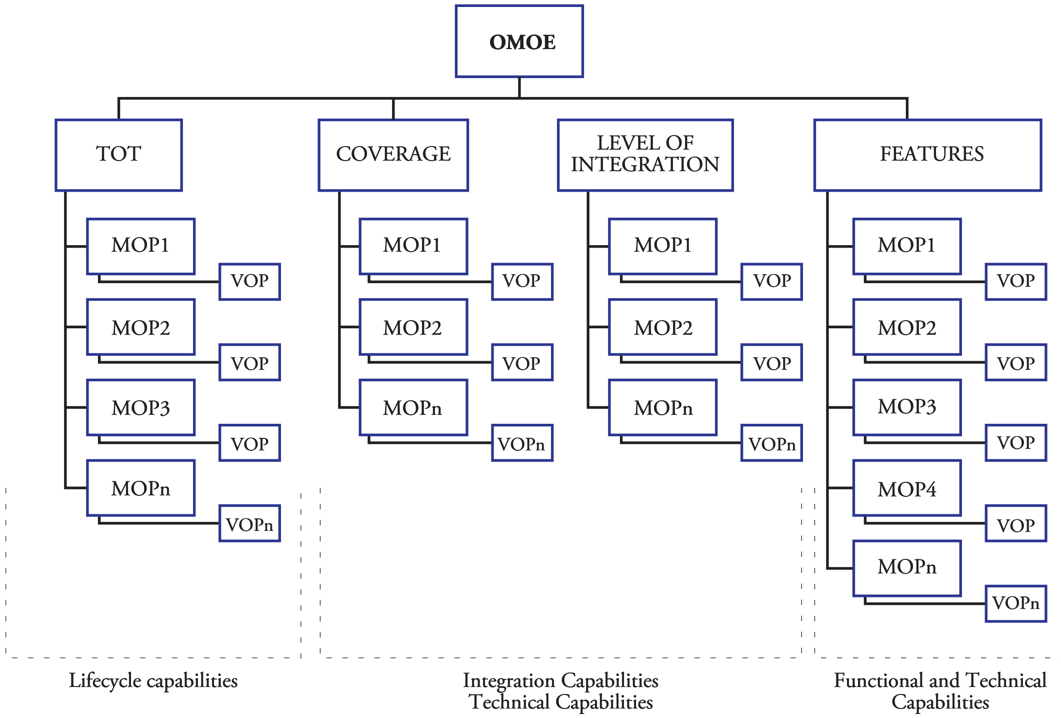
- Technology Transfer (ToT): groups the most significant aspects associated to transfer of knowledge and *Know How*, which will be evaluated from the proposals.
- System Coverage: groups the aspects associated to the types of units and desired quantities for the system prototypes.
- Integration Level: groups the relevant aspects, associated to the minimum requirements desired for integration and interconnection at a system level and its relation with existing systems in each unit.
- Functionalities: groups aspects associated to function, profit, and operation capacities of the system, per the operational needs of the ARC.

Fig. 4 presents the general outline of the effectiveness model, where the association between affinity groups, the performance measurements and the quantitative measurement of alternatives may be seen. In the same way, the capacities to be obtained by ARC and COTECMAR during the development of the project, may also be seen.

Different MOPs are determined for each affinity model, which are divided into two groups: qualified and quantified. Quantified are those associated to numerical values within the model, while qualified, are those MOPs that are not directly measurable, therefore, making it necessary

[1] The affinity groups are a set of performance measurements considered to evaluate each one of the alternatives.

Fig. 4. Histogram of ballast water reception tanks



to consider options or technological alternatives that may be numerically evaluated and that allow for the evaluation of the presented proposals.

A continuous o discrete value curve is selected for each one of the technological options proposed. Their corresponding superior and inferior limits are suggested for the case of continuous curves and ponderations in the case of discrete curves.

The ponderation of the different MOPs is done by the first Group of experts, as of the cross-check of pairs, taking as a reference model the AHP methodology. This weighing allows to identify the level of relevance of a MOP compared to another and to translate this importance into a coefficient or numerical value. This relationship is seen by:

$$MOE = w_1 * MOP_1 + w_2 * MOP_2 \ldots w_n * MOP_n \qquad (1)$$

Risk Model

Taking as reference what was established in [3], the different areas of risk stated below are defined:

- Threat
- Requirements
- Design
- Test and evaluation
- Simulation
- Technology
- Logistics
- Production/capacity
- Concurrence
- Capacity of the developer
- Cost of technology/financing
- Schedule/timeline
- Technology management

Although these areas are not the only ones applicable to the type of Project, it is possible to determine similarities among risk events and classify them within them. These events will constitute the aspects to be assessed within the risk model of the Project, considering the performance, timeline and associated costs to the different alternatives. According to [3], the criteria of level of probability of occurrence, P_i, are applied to the levels presented in Table 1.

Table 1. Criteria of level of probability of occurrence, Pi

LEVEL	DESCRIPTION
0.1	Remote
0.3	Improbable
0.5	Probable
0.7	Highly probable
0,9	Almost surely

In the same way, the level of impact (C_i) for each risk event is considered in a scales that varies between 0,1 (minimum) and 0.9 (unacceptable).

Finally, to obtain the OMOR, the values for the MOPs associated to the risks that impact the development of the project are extracted from the effectiveness model. Later, the pairs are compared to obtain a relevance relationship between the risks associated to performance, timeline, and cost. This comparison defines the importance of each one of these three measurements associated to the total measurement of risk, which is finally obtained in function of the following equation 2.

$$OMOR = W_{perf} \frac{\sum_i P_i C_i \cdot w_i}{\sum_i (P_i C_i)_{max} \cdot \sum_i w_i} + \frac{\sum_j P_j C_j}{\sum_j (P_j C_j)_{max}} + W_{sched} \frac{\sum_k P_k C_k}{\sum_k (P_k C_k)_{max}} \qquad (2)$$

Where:

i: Risks associated to performance
j: Risks associated to cost
k: Risks associated to timeline
P: Probability of occurrence
C: Impact
W: Ponderation of the type of risk
w: Ponderation of the risk associated to performance

Cost Model

The general measurement for cost or OMOC, is used to analyze the different alternatives and evaluate the costs required by COTECMAR-ARC. This model does not intend to forecast a final cost value for the project, since it is not a cost estimation exercise, however, the activities for each alternative are evaluated according to their associated cost. In the same way, to generate the model, both direct and indirect costs are analyzed and three main levels are established for evaluation:

Association Cost (C_a)
Direct cost of the association required for the development of the Project. Includes the cost related to goods and services, taxes and nationalization.

Cost of participation (C_p)
Direct and indirect costs associated to the contribution of COTECMAR-ARC to fulfill the work schedule, equipment delivery plan, training, on-site work training and development process.

Likewise, the costs associated to the technology transfer process are considered and those that allow for the comparative analysis between the different proposals. An analysis is made for the following costs:

- *Personnel:*
  Associated to the staff that participates in the development activities and transfer of technology. The estimation of this value is done, considering the number of people, number of days and location.

$$C_{pp} = f_{pl}([n_p, n_t],[t_p, t_t]) + f_{pn}([n_p, n_t],[t_p, t_t]) + f_{pe}([n_p, n_t],[t_p, t_t]) \qquad (3)$$

Where:

C_{pp}: Cost of participation personnel category
f_{pl}: Cost of local participation.
f_{pn}: Cost of participation at a national level out of the city of origin.
f_{pe}: Cost of participation abroad.
n: number of people that participate (p: professional, t: technical).
t: duration time of participation.
z: area where the activities are to be developed (only abroad)

- *Initial training:*
  Preparation of the staff that participates in the process of technology transfer during the development of a project. To calculate the cost of this training, average market values are used to cover the area of interest.

- *Hardware and Software:*
  Correspond to the use of computer equipment and software during the technology transfer activities.

Cost of life cycle (C_v)

Costs projected in time, associated to activities resulting from the process of technology transfer. These costs must be projected along the entire life cycle of the system and represented in present value. The costs associated to the use cycle[2] of the naval system to be developed and the maintenance costs (C_m) and training costs (C_e) are identified as the most relevant to calculate the OMOC. Although this analysis doesn't only include these cost areas, they are considered the most relevant capacities to acquire through technological transfer and allow to indicate significant changes among the different alternatives.

The cost of life cycle (C_v), is expressed as:

$$C_v = C_m + C_e \tag{4}$$

- *Maintenance (C_m):*
  Maintenance activities are classified into 5 different levels according to the degree of intervention in the system and the maintenance classification specified in [5]. The associated cost to each level corresponds to the amount of work hours associated to maintenance activities, frequency for this type of maintenance and vale of hour per person. To assess maintenance, the percentage of capacity is specified from each one of the maintenance levels.

$$C_{mi} = (Q_m * C_{ml} + (1 - Q_m) * C_{me}) * f * t \tag{5}$$

Where:

C_{mi}: Cost associated to maintenance in level i
Q_m: Acquired maintenance Capacity
C_{ml}: Cost of local workforce
C_{me}: Cost of external workforce
f: Yearly frequency of the maintenance cycle
t: Duration of maintenance operations

Finally the maintenance cost is calculated C_m as the addition of the cost of the 5 levels.

$$C_m' = \sum_{i=1}^{5} C_{mi} \tag{6}$$

This cost, projected to the number of years in the useful lifecycle is transferred to present value, with a profitability equal to the average DTF for the past years, and it is shown in Equation 7.

$$C_m = \sum_{p=0}^{a} C_m' * (z)^p \tag{7}$$

z: factor dependent on the number of years (a) and inflation.

- *Training (C_e):*
  The level of obtained capabilities is used, by estimating the costs associated to training, in this case, the level of capabilities acquired to render future training throughout the lifecycle of the system, in three different levels of training: basic, intermediate and expert.

For the specific case of the applied project, it is represented by a linear equation of the training costs in function of time $f(t)$. This way, the cost of training done by an external agent is expressed as:

$$C_{eei} = f(t) * n * F \tag{8}$$

Where

C_{eei}: Annual cost of training by an external agent in the i- est level
t: Training duration
n: Number of people trained
F: Annual training frequency

[2] Generally, the life cycle of a system may be described in the design, production, commercialization, use and dismantling stages.

The final assessment of this measurement is expressed as follows:

$$C_{ei}(Q_e) = \sum_{1}^{l} (Q_e * C_{eli} + (1 - Q_e) * C_{eei}) \quad (9)$$

Where:

Q_e: Acquired Capability to conduct training at the i- est level
l: Number of training levels

This cost is projected to a specific number of years and brought to present value.

$$C_e = \sum_{p=0}^{a} C_e' * (z)^p \quad (10)$$

z: factor dependent on the specific number of years (a) and inflation.

The calculation of OMOC is done through the arithmetic addition of each one of the types of costs described:

$$OMOC = C_a + C_p + C_v \quad (11)$$

Application of the model

To obtain the results from the application of the model, five (5) possible scenarios are designed, where each alternative is evaluated and the obtained ponderations are analyzed. Each assessment offers an aid in decision making considering the available budget and the capabilities that COTECMAR-ARC aims to obtain.

Likewise, a desirable range for each one of the measurements of effectiveness, risk and costs is determined, thus filtering the alternatives that do not comply with the following restrictions:

- Effectiveness: obtained value higher than 60%
- Cost: between 20% and 40% of the available Budget for the association.
- At Risk: medium, low and very low risk index.

For the risk index, four ranges are set: Very low (less than 25%), low (26% - 50%), medium (51% - 75%), high (higher than 75%)

Fig. 5 presents the results of the alternatives assessed in the different proposed scenarios which comply with the established restrictions. The graph shows the effectiveness value in the vertical axis, a cost value in the horizontal axis, provided as a percentage related to the highest cost activity and a risk value represented by a color associated to its ponderation.

The highlighted points in the dotted area, show the options that have a higher possibility to be selected because they represent an effectiveness-cost-risk relationship that is favorable and valid to develop the project.

It is noteworthy to state that this model and the results obtained from the assessment, offer great help for decision-making, however, the selection of the alternative is done in function of the analysis of correlation between OMOE, OMOR and OMOC.

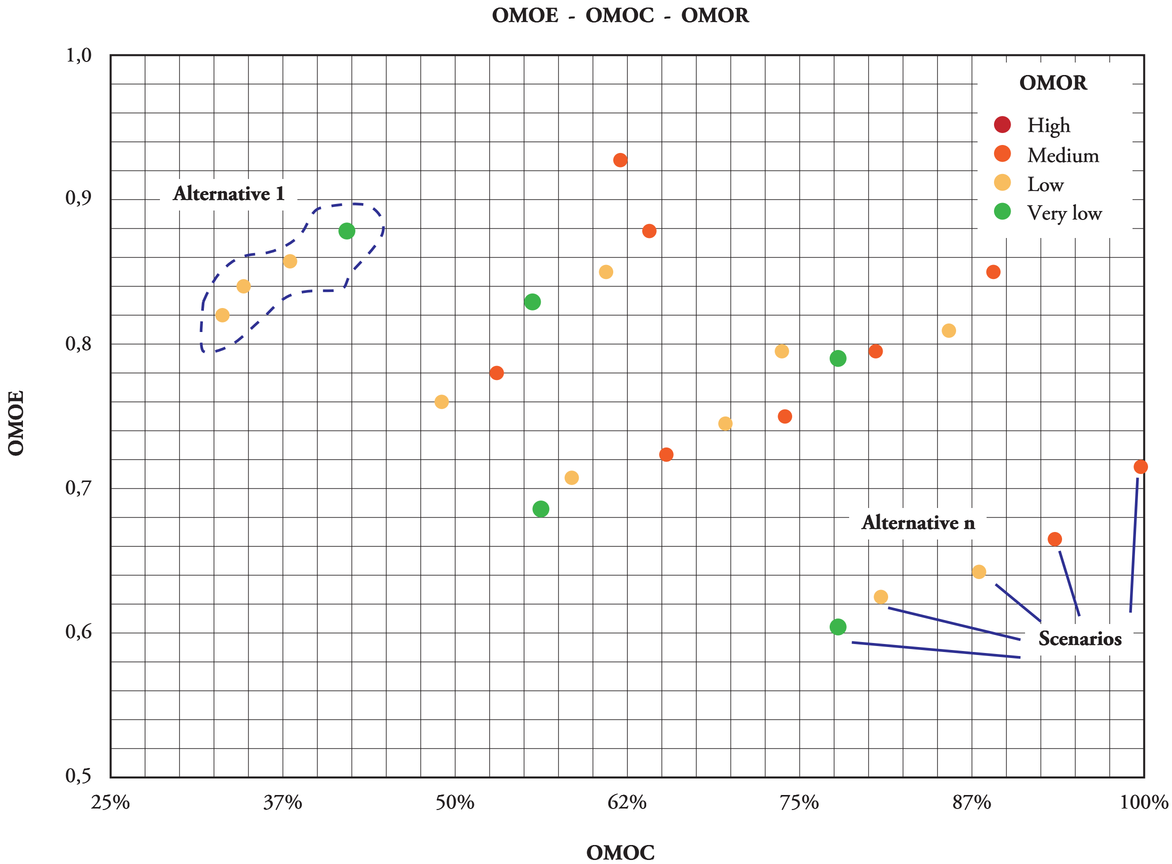
Conclusions

The application of the methodology for the design of assessment models presented in this document, results in a reduced Group of alternatives which best adjust to the Budget, risk and desired scope conditions, for the execution of projects, making it easier to make decisions that aim to acquire the capabilities of development of naval systems at ARC-COTECMAR.

The effectiveness, cost, and risk are observed as different attributes that use different measurement units, for which they cannot be rationally combined to produce one sole objective function.
This entails that they are presented individually but simultaneously, in an easily manageable format that allows for interaction between them, easing decision-making.

This format is a space for selection, where the alternatives may be graphed out as points, using the values obtained for effectiveness, cost and risk

Fig. 5. Selection Alternatives



as coordinates, thus offering a perspective that aids at the moment of decision-making.

In general, the methodology proposed by [2] and [3] may be applied to any type of Project, considering the different measures and factors to evaluate, taking into account the risk and cost in the development and the nature of the project.

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[5] AFNOR, FD X 60-000, ISSN 0335-3931, Francia, Mayo
2002.

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