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Editorial Note

Cartagena de Indias, July 30th, 2020.

For our Corporation and the **Ships Science and Technology Journal**, the challenges imposed by the global pandemic situation have been many, from them we have learned how to adapt to unexpected changes that force us to be flexible and resilient for continuing in the achievement of the objectives set. This has led us to reschedule the *VII International Ship Design and Naval Engineering Congress - CIDIN 2021* for September, keeping its location in the historic Cartagena de Indias, an event in which everyone is invited to participate.

For this new edition of the magazine, we present topics related to the preliminary design of a management maintenance model of sensitive engineering assets; the Current and Potential Contribution of the Colombian Ministry of Defense to the National River Master Plan and the Accomplishment of the Sustainable Development Goals through COTECMAR; Calculation of the Specific Attenuation in Satellite Bands Due to the Rain in the City of Cartagena and its Importance in the Naval Field; the Design and Structural Analysis of a SWATH type vessel using the Finite Element Method and its response to Slamming events; Jib crane bearing selection through simulation; and A Preliminary Study of Routing Protocols in a Tactical Data Link Ad Hoc Network in Colombian Maritime Scenario.

We hope that these topics will be of your complete interest and serve to transfer part of the achievements and developments that our Corporation makes to contribute to the scientific and technological development of the country and at the same time, serve to motivate you to be participant and protagonists of our next editions.

May this be the propitious occasion to reiterate our best professional and personal wishes to all our readers in these difficult times, hoping in the near future to have the opportunity to meet you personally at the different events of our naval engineering community.

Cordially,

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

Nota Editorial

Cartagena de Indias, 30 de julio de 2020.

Para nuestra Corporación y la **revista Ciencia y Tecnología de Buques** los retos impuestos por la situación pandémica mundial han sido muchos, de ellos hemos aprendido a adaptarnos ante cambios inesperados que nos obligan a ser flexibles y resilientes para seguir avante en el cumplimiento de objetivos trazados. Esto nos ha llevado a reprogramar el *VII Congreso Internacional de Diseño e Ingeniería Naval CIDIN 2021* para el mes de septiembre, manteniendo su sede en la histórica Cartagena de Indias, evento en el cual están todos invitados a participar.

Para esta nueva edición de la revista, presentamos temas relativos al diseño preliminar de un modelo de gestión de mantenimiento de activos bajo el concepto de ingeniería de confiabilidad; la contribución actual y potencial de nuestro Ministerio de Defensa al Plan Maestro Nacional Fluvial y al cumplimiento de los Objetivos de Desarrollo Sostenible; el cálculo de la Atenuación Específica en Bandas Satelitales por lluvia en Cartagena y su Importancia en el Campo Naval; el diseño y análisis estructural de un barco SWATH por el método de elementos finitos y su respuesta a cargas de impacto; la selección de rodamientos mediante simulación para un brazo de carga; y finalmente el estudio preliminar de protocolos de enrutamiento en una red ad hoc de enlace de datos tácticos en el escenario marítimo colombiano.

Esperamos que estos temas sean de su completo interés y sirvan para transferir parte de los logros y desarrollos que nuestra Corporación hace para contribuir al desarrollo científico y tecnológico del país y a la vez los motiven a ser partícipes y protagonistas de nuestras siguientes ediciones.

Sea esta la ocasión propicia para reiterar nuestros mejores deseos profesionales y personales a todos nuestros lectores en estos tiempos de complicaciones, esperando en un futuro cercano, tener la oportunidad de encontrarnos físicamente en los diferentes eventos de nuestra comunidad de ingeniería naval.

Cordialmente,

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

Preliminary design of a management maintenance model of sensitive engineering assets, for a ship under the concept of reliability engineering

Diseño preliminar de modelo de gestión de mantenimiento de activos sensibles del área de ingeniería para un buque naval bajo el concepto de ingeniería en confiabilidad

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Abstract

The objective of this research is to apply a dynamic maintenance model to the assets of the engineering department of a navy vessel, based on the concept of reliability engineering, which analyzes the statistics of failures of different equipment, in a period of 140 months, in order to determine which is the most sensible equipment, the failure modes and the impact it produces on the ship's platform. This way, it is possible to focus on the problems that produce the biggest impact in the capacity of the Unit´s, in order to fulfill its roles, and this way, contribute increase its availability. This is an iterative process of continuous improvement for the maintenance plans.

Key words: Condition Based Maintenance (CBM), Failure Mode, Effects and Criticality Analysis (FMECA), Key Performance Indicator (KPI), Reliability Centred Maintenance (RCM), Maintainability, Reliability.

Resumen

La presente investigación tiene como propósito aplicar un modelo de mantenimiento dinámico a los activos del Departamento de Ingeniería de un buque tipo naval basado en Ingeniería en Confiabilidad, el cual analiza la estadística de falla de los equipos durante un período de 140 meses para determinar la maquinaria más sensible, además de los modos de falla y el impacto que produce en la plataforma. De esta manera, fue posible concentrarnos en los problemas que producen un mayor impacto a la capacidad de la Unidad para cumplir sus roles y contribuyendo de esta manera a aumentar su disponibilidad. Éste es un proceso iterativo que busca generar una retroalimentación entre las acciones de mantenimiento con el propósito de establecer un proceso de mejoramiento continuo en los planes de mantención.

Palabras claves: Mantenimiento basado en la condición (CBM), Análisis de modo de falla, efecto y criticidad (FMECA), Indicadores de desempeño (KPI), mantenimiento basado en la confiabilidad (RCM), Mantenibilidad, Confiabilidad.

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Introduction

At the end of the last stage of the renewal of naval equipment, the incorporation of new units brought as a consequence the incorporation of new technologies. For engineering some advances were incorporated, for example, the replacement of steam propulsion with combined systems using diesel engines, gas turbines, electric motors, among other types of machinery.

But, as new types of technologies were incorporated, it also implied greater training for both operators and system maintainers, which also called for a modernization of maintenance policies in order to have availability of the Units that allows defending national sovereignty whenever the country requires it.

For this, the present investigation aims to implement a model of dynamic maintenance to the assets of the Engineering Department of a naval ship, based on engineering in reliability, which analyzes the statistics of failure of machinery equipment to determine the most sensitive, in addition to the failure modes and the impact on the platform.

In this way, it seeks to optimize maintenance efforts, concentrating on the problems that produce a greater impact on the capacity of the Unit to fulfill its roles and thus, contributing to increase its availability. This is a continuous and iterative process that seeks to generate feedback between maintenance actions and equipment failures, in order to establish a process of continuous improvement in maintenance plan.

Theoretical framework of research

Reliability engineering

The organizations have felt the need to improve all the techniques related to the management of their assets. That is why reliability engineering was born as a way in which these processes can be optimized through effective and efficient maintenance policies developed based on pieces of equipment that directly affect their availability or productivity. From this perspective, the system that is under investigation must be able to answer the following questions: what are the functions of a piece of equipment?, in what way can it fail?, what causes it to fail?, what happens when it fails? What happens if it fails? What can be done to prevent failures? and finally, what happens if the failure can't be prevented? These questions were summed up by Moubray (2004) for the study of Reliability Engineering based on the RCM.

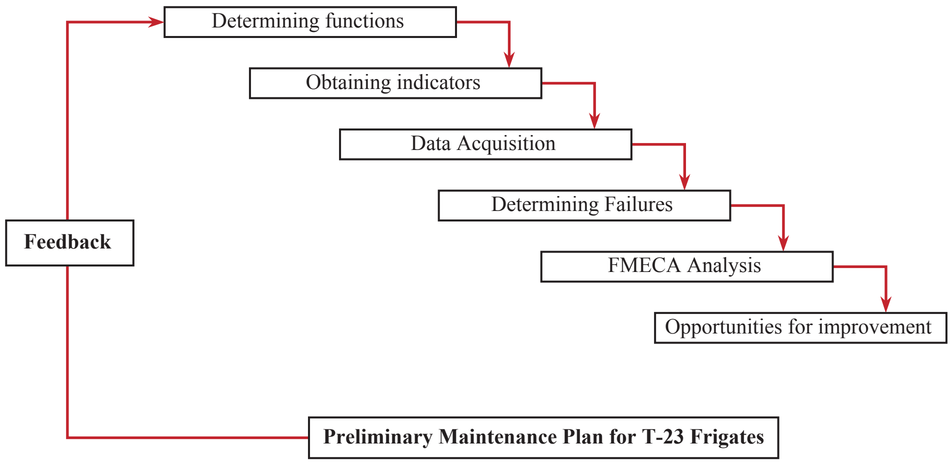
With this questioning, the Engineering in Reliability allows to delve into concepts related to the reliability, maintainability and availability, all based on statistical resources for the analysis or evaluation of improvements, design, forecasting and maintenance of the machines to reduce costs and obtain customer satisfaction regarding to the equipment. For this, the phases that will be mentioned below must be carried out.

Stage 1: List of functions. In this incipient stage it is necessary to identify and define the primary functions (those that fulfill the main task the asset was acquired for) and/or secondary (additional tasks) of the systems of a company or institution associated with a specific area, in order to contextualize their operation.

The logical-functional representation of the system will be preponderant through the creation of block diagrams known as RBD (Reliability Block Diagram), with which it is possible to perform a graphical analysis of the connection of components according to their logical relationship.

Stage 2: Obtaining performance indicators. Once the historical background associated with its logical-functional representation has been obtained, it is necessary to establish performance indicators also known as KPI or key performance indicators that allow the identification of cost reduction, improvements in processes and productivity. *For example:* the frequency of failure or MTBF, unscheduled downtime, level of impact to the operation (percentage given by the user) and/or reliability.

Fig. 1. Stages of Reliability Engineering [Own Development].



Each institution or organization must be able to establish the characteristics and/or parameters that will contribute to the identification of the sensitive equipments of each organization, and it will finally contribute to the determination of where to focus the efforts to perform the Failure mode, effects and criticality analysis (FMECA).

Stage 3: Data acquisition. Each organization must have a complete list of their equipment, classified into main or auxiliary systems, which must be hierarchized according to the consequences they have on the operation of the company and/or institution through a survey of historical data that "results from both planned and unplanned detentions, of both the maintenance and operation of the plant or fleet under study" *(Arata, 2013, p.121)*.

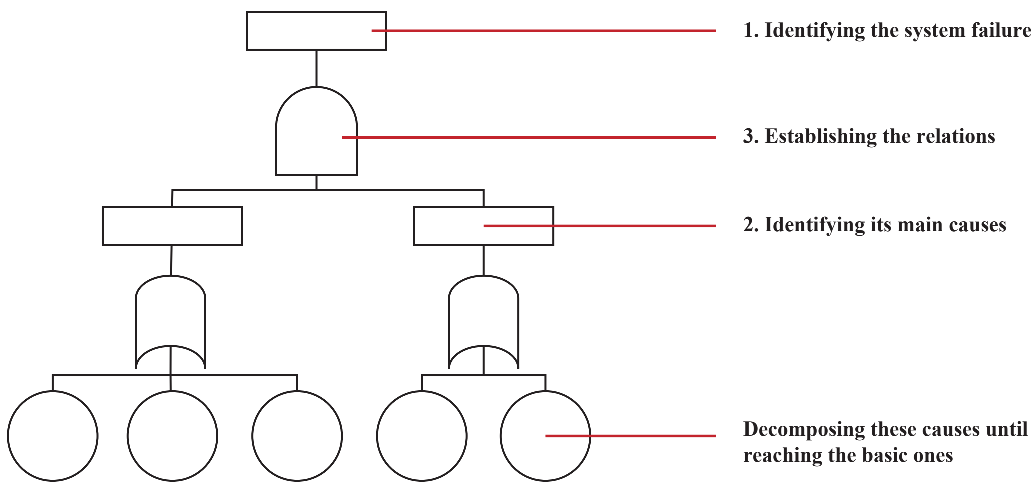
Stage 4: Determining failures. Failures are defined as "the inability of a good to fulfill the functions that the user expects it to perform" *(Moubray, 2004, p.45*), since it has caused an alteration in the components or in the operation. The study considers both the main faults that prevent the system from fulfilling its function and the secondary faults which do not make the operation of the equipment impossible, but supposes an abnormal operation.

Stage 5: Determining modes of failure (FMECA). The FMECA is specified as "a qualitative and structured analysis performed on a system, subsystem or function, used to identify their potential failure modes, their causes and their effects associated with each of those" *(Bowels and Bonnell, 1998, p.2)* in order to determine new policies and avoid unscheduled stops in case of failure. Therefore, the failure modes are all those events or reasons that can generate a functional failure in the system, such as the causes related to the design, assembly, the state of a component, the operation, maintenance failures, abnormal external conditions or as a result of another malfunction.

In order to establish an adequate strategy for the management of failures, it is necessary that each mode contains enough details so that a finished analysis can be carried out at different depth levels. A useful way to study the modes can be through the following strategies:

Failure Tree Analysis (FTA). It is a deductive process used to determine the combinations of failures by conditions such as diminution of systems performance, safety or other operational attributes that have the potential to contribute to their occurrence. It can also be used to calculate the probability of occurrence of a main event of failure using analytical or statistical methods, contemplating the probability of basic events in a time interval.

Fig. 2. Failure Tree Analysis.



Pareto Analysis. This analysis is a quantitative comparison of factors in a higher to lower fashion according to their contribution to a given effect. It is represented by means of a histogram, in which the factors are classified as "unimportant" (very important elements) to the "very trivial" (the unimportant elements). With this graphical representation of a Pareto Analysis, it was concluded that 20% of the causes generate 80% of the total faults.

Root cause analysis. An analysis in which the causes of failures are identified to avoid their recurrence through a process that aims to achieve continuous improvement. This methodology functions to reveal problems and solve them, so the difficulty must be dealt with exhaustively on each of the actions that could have generated the failure.

Ishikawa's Chart. It is a cause - effect diagram that consists of the graphic representation of a

Fig. 3. Example of a Pareto chart.

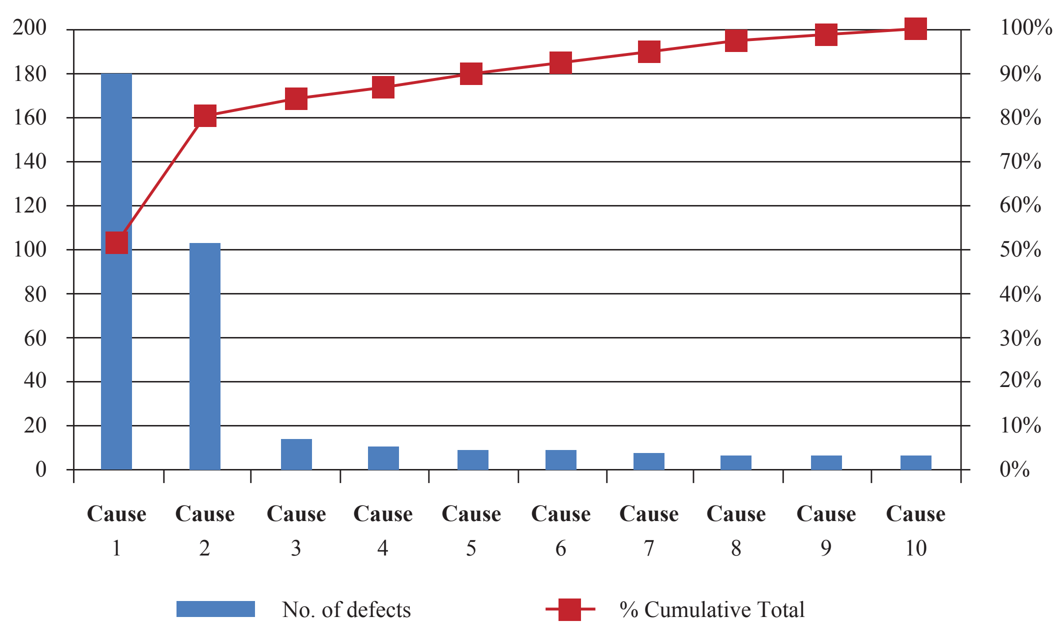
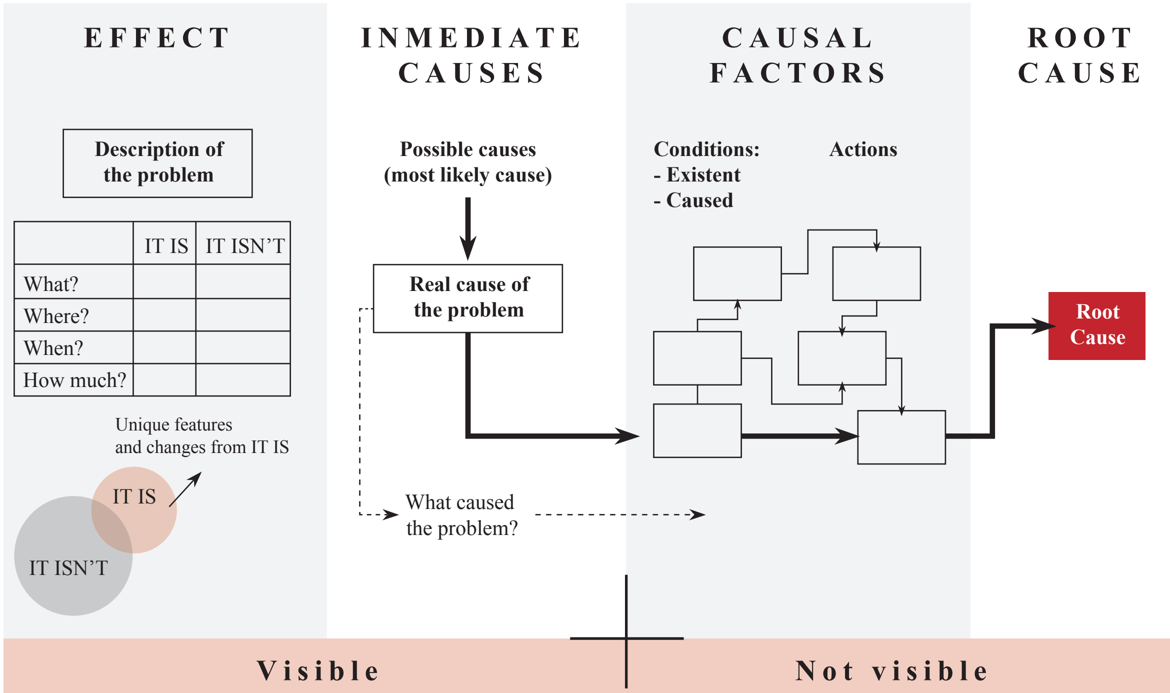


Fig. 4. Root Cause Analysis Chart.

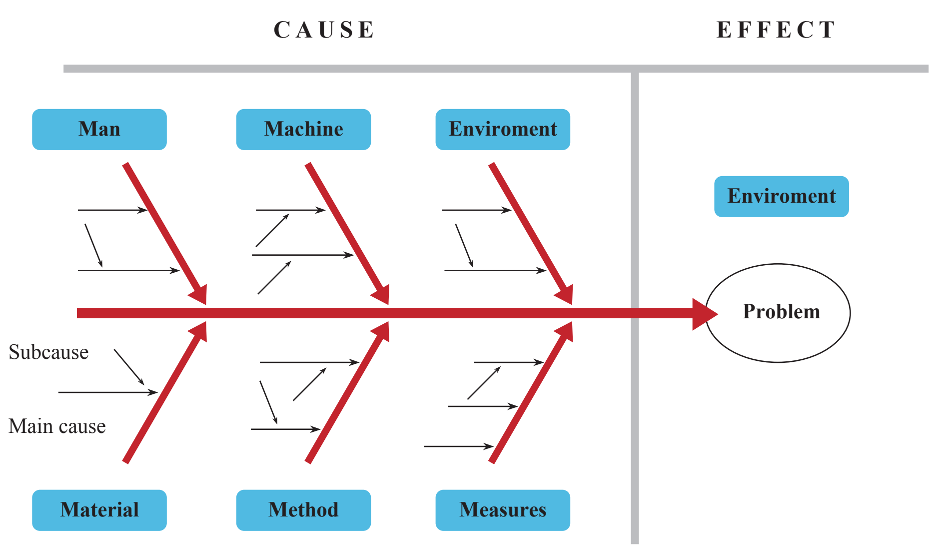


problem in the horizontal plane, representing the problem to analyze, with its respective causes as it is taught (see Fig. 5).

Stage 6: Analysis of effect and criticality (FMECA). Once the failure modes have been identified, it is necessary to know the consequences and the criticality of these, since, when evaluating the importance of each failure. It is necessary for Engineering in Reliability to assess the following three aspects *(García, 2015, p.145)*:

Evidence of a failure. Sometimes some flaws may be hidden in the system, because they do not have any symptom that could be evidence for this. Apparently, they do not have consequences

Fig. 5. Ishikawa's Diagram [16].



until they become dormant or until they lead to multiple failures. This is different when the fault is detectable from the moment it occurred.

Criteria of consequences of failure.

Personal Safety

Table 1. Consequences for personal safety [10].

Rating	Consequences
Very Serious	Considerable personal damage.
Serious	Minor personal injuries.
Mild	No possibility of personal injury.

Environmental Impact

Table 2. Consequences for environmental impact [10].

Rating	Consequences
Very Serious	Irreversible damages, repairable with high cost or violation of an environmental standard.
Serious	Environmental damage with affordable cost.
Mild	No possibility of environmental damage.

Production

Table 3. Consequences for production [10].

Rating	Consequences
Very Serious	Stoppage of production greater than 48 hours. Reduction of the production of activities superior to 25% during more than 48 hours.
Serious	• Impossibility to fulfill the loading program less than 48 hours. • Reduction of production of activities less than 25%.
Mild	It does not affect production.

Repair Costs

Table 4. Consequences for personal safety [10].

Rating	Consequences
Very Serious	High cost failure.
Serious	High cost reiterative failure.
Mild	Low cost failure.

Probability that the failure will occur

Table 5. Probability of Failure.

Rating	Consequences
Highly Likely	Failures that will occur before two years if no measures are adopted.
Not likely	Failures that will occur after five years.
Highly unlikely	Low probability that it happens.

The combination of the weights in each of the three conditions will allow faults to be classified into four categories: insignificant, bearable, significant and critical failures typical in sensitive equipment identified by each organization). This is just one of the many examples for the creation of a risk matrix.

Stage 7: Preventive measures. In this stage the preventive measures to be adopted must be determined to avoid any potential failures *(García, 2015, p.149)*, such as: implementation of improvements and modifications in the installation, modification of operation and maintenance instructions, scheduled maintenance tasks, training for operators and users.

The maintenance task can be classified in:

- Basic tasks such as sensory inspections, reading and history of parameters, lubrication and replacement of parts with low cost.

- Significant tasks corresponding to the basic tasks plus parameter measurement with external elements, verification (clearance, alignment, tightening, among others), replacement of parts in wear and clean condition.

- Systematic tasks that constitute the sum of the previous tasks (basic and significant) plus the calibration of measuring instruments, reengineering and systematic replacement of wear parts.

Stage 8: Grouping of measures. Prior to the implementation of the measures and with the aim of facilitating this task to avoid potential failures in the machinery, they are grouped into the following categories: list of preventive measures in case of failure, maintenance plan according to modifications, training and spare parts list.

Stage 9: Implementation and monitoring. Once the previous phases have been concluded, the analysis and economic evaluation of the identified improvement opportunities must be executed to be subsequently defined in a global asset management and implementation plan. The idea of this procedure is to be constant feedback to generate continuous improvement.

Methodological framework of the investigation

General Background

From a methodological point of view, this work was identified as an Applied Research (also known as practical or empirical). That is, by means of the knowledge acquired in addition to the results of the work generated a rigorous, organized and systematic way of knowing the reality which allowed the preliminary design of improvements to the maintenance plan for the naval ship in which tools were used such as data analysis, failure rates and respective criticality to investigate, analyze and determine improvements to a given system.

Description of the research strategy

Through this work we sought to study "the effects of current naval ship maintenance policies on the availability of the Unit" with the aim of providing new technical criteria to finally establish a preliminary design of improvements to the plan of current maintenance using Reliability Engineering.

Therefore, the developed strategy was the methodical study of the failures from the point of view of Engineering in Reliability. This analysis process allowed us to apply measurement parameters and data analysis through the implementation of the four stages described below:

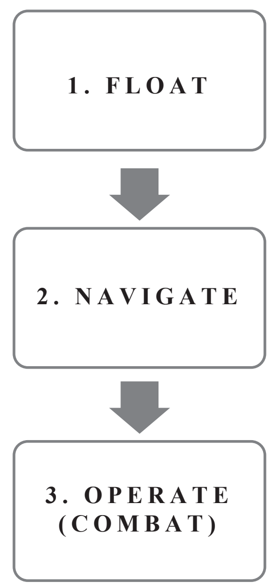
Stages of the research

Stage 1 "Determining Sensitive Equipment".

Phase 1: Functional logical configuration.

Methodology. For this first step it is necessary to define the functions that pertain to the ship's engineering systems, with the purpose of contextualizing its operation according to three pillars that the Combat Units must comply with.

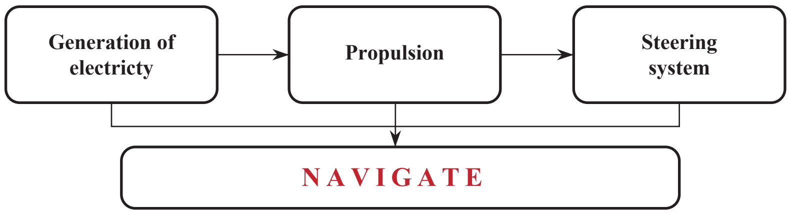
Fig. 6. Ship Functions.



Once hierarchized, it is essential to associate these capabilities with the block diagrams (RBD) of the existing engineering area systems on board the Unit from the point of view of a functional configuration. That is, to establish a logical-functional representation that allows to graphically identify the interdependence of different equipments in front of the aforementioned functions. Broadly speaking, an example of the above is shown in Fig 7.

Information Analysis. For the development of this phase, the hierarchy of the functions of floating, navi-gating and operating was defined. Undoubtedly, the most important function in a ship is to "float", since otherwise it would be

Fig. 7. RBD Chart example.



impossible to develop any of the other functions. Then the "navigating" function was considered as a secondary function, since the analysis was carried out from a logistical perspective and, finally, the task was to operate.

The systems of the ship are oriented so that they can comply with the aforementioned functions; in this way certain dependencies are generated between the systems, which cause the failure in one of these to prevent the Unit from being able to develop a specific function. For example, for the function to navigate it is necessary that at least the motor, the line of axis and the propeller are operational, otherwise, the ship will not be able to fulfill its operational role.

As a result of this, the block diagrams of the naval ship's equipment were elaborated based on their configuration and reaching up to the third level defined in the Manual of Codification of the Ship's Components Systems.

The dependence of these systems and the function to which they are associated that will affect later to determine how sensitive they are according to the function that allows them to develop, was appreciated. It is important to mention that for the purposes of the study, the "float" function was dispensed with, since it has little associated failure statistics.

Phase 2: Performance indicators.

Methodology. For this phase, the KPIs (Key Performance Indicator) should be selected to provide information regarding the performance of the systems of the Naval Ship Engineering Department, with the objective of making a diagnosis of the reliability and availability of the Sensitive Equipment.

Results of the investigation. The performance indicators selected for this work are:

- Failure rate: A performance indicator that shows the percentage of failures of each of the functional elements with respect to its total.
- Criticality: An indicator used to rank teams according to the impact they cause in the Unit. From the mathematical point of view, the product is obtained between frequency (number of events or failures) and the value associated with the consequences in terms of their operational impact, which can be classified from a logistical or tactical vision, depending on the high level requirements for the fleet.

Phase 3: Data Acquisition.

Methodology. The collection of historical data, both from the planned stoppages and those that happened unexpectedly on the naval ship, was carried out by means of the collection of information extracted from the historical record of failures.

To this end, the failures of the Engineering area of three naval vessels of the same type (mentioned as BN 1, BN 2 and BN 3 to maintain the reservation of their names during the investigation) were considered over a period of 140 months, specifically, between the January 1, 2007 to May 31, 2016, adding a total of 4,396 which are divided into:

Table 6. Failures in Type 23 Frigates [Own Elaboration].

Unit	No. of failures
BN 1	1.126
BN 2	1.407
BN 3	1.863

Results of the investigation Of the 4,396 failures linked to the Departments of Engineering of naval ships, it can be seen that.

Information Analysis. Based on the previous table, a histogram was generated that represented the statistical behavior of the faults of the naval ships, having a greater tendency in the Auxiliary Systems (53.55%), Propulsion Plant (31.37%) and Plant Electrical (7.96%), concentrating in these 92.88% of the total cases, which are related to the systems that contribute in the fulfillment of the functions of floating and navigation mentioned in predecessor phases. The rest of the groups, although they fulfill a certain role in the Unit, did not have a greater incidence in this investigation.

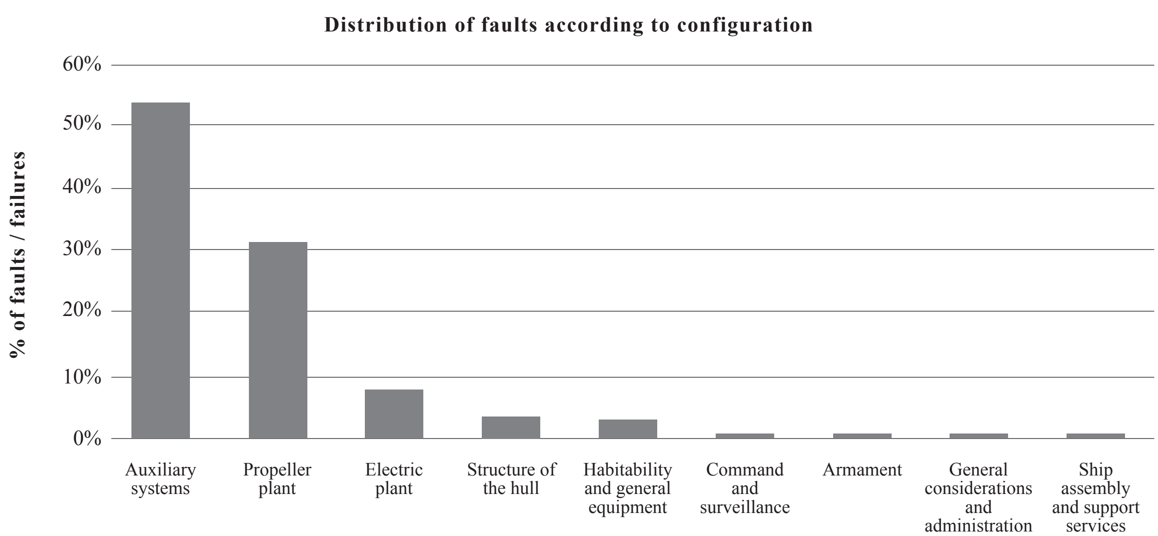
Phase 4: Determination of sensitivity of assets.

Methodology. As it was mentioned before, the statistical analysis of failures included the study of 4,396 events, whose data in this particular phase were grouped by means of Pareto Diagrams or Histograms, and analyzed from three perspectives:

Table 7. Distribution of the failures of the three naval ships [Own Elaboration].

Group	Name	No. of Failures
00000	General considerations and administration	2
10000	Structure of the hull	151
20000	Propulsion plant	1.379
30000	Power plant	350
40000	Command and surveillance	10
50000	Auxiliary systems	2.354
60000	Habitability and general equipment	142
70000	Armament	6
90000	Ship assembly and support services	2

Fig. 8. Fault histogram according to configuration [Own Development].



number of faults linked to assets, relative frequencies (percentages of failures in each equipment) and accumulated frequency (percentage of failures that are added up to complete the absolute 100%).

From the table described in Phase 3 "Acquisition of data" it was possible to identify and quantify not only those equipment with a high failure rate, but also those functional elements that constitute it and whose accumulated percentage was transcendental to determine those assets that grouped 50% of these.

With this information, the hierarchy process was originated through the use of two types of coefficients, one by frequency and the other by the criticality in the process they develop. The multiplication of both factors, finally, gave the order to the importance (sensitivity) of the equipment to delimit those sensitive assets that were the object of the FMECA study.

Results of the Investigation. Out of the more than 4,000 faults, information was grouped into a total of 269 equipments. The variations of the frequencies in the functional elements ranged from the 793 failures for Team 1 to a failure for other equipment, so there was a wide range of distribution.

To analyze the amount of information obtained, for this phase the cumulative frequencies (% ac.) up to the second quartile were considered, concentrating the data on 13 functional elements (See Table 8).

Information Analysis. An important part of the work of this phase was executed when ordering the information of the record history since it was possible to determine the amount of events associated to the Engineering teams of the naval ships. However, another part of the objective was to specify the sensitive assets related to these faults, so it was necessary to carry two filters for their selection. The first one was carried out when selecting the 13 functional elements (out of 269) whose percentage of failures accumulated up to 50% of the total and the second by means of frequency, function and sensitivity indicators.

Coefficient of Frequency (F). As explained above, the wide range of frequencies for each of the systems represented a difficulty when calculating them criticality. If the nominal statistical values were considered, the frequency coefficient would have an equally dispersed behavior to the number of faults, distorting definitively the information at the time to carry out the selection.

Therefore, the frequencies of the data were distributed into 5 groups in intervals of 160 faults each, completing a total of 800 at the last level. Each rank was associated with a number from 1 to 5 in ascending order (See Table 9).

Table 8. Faults of Naval Ships. (frequency accumulated up to 50%).

Functional Element	No. of Faults	%	% ac
Equipment No. 1	793	18,04%	18,04%
Equipment No. 2	218	4,96%	23,00%
Equipment No. 3	209	4,75%	27,75%
Equipment No. 4	173	3,94%	31,69%
Equipment No. 5	170	3,87%	35,56%
Equipment No. 6	135	3,07%	38,63%
Equipment No. 7	93	2,12%	40,74%
Equipment No. 8	84	1,91%	42,65%
Equipment No. 9	81	1,84%	44,49%
Equipment No. 10	68	1,55%	46,04%
Equipment No. 11	68	1,55%	47,59%
Equipment No. 12	67	1,52%	49,11%
Equipment No. 13	64	1,46%	50,57%

Table 9. Frequency factor.

Intervals	Frequency Coefficient
1-160	1
161-320	2
321-480	3
481-640	4
641-800	5

Function coefficient (V). The systems must be able to contribute to the fulfillment of the functions of floating and navigating of the Combat Units, each of them with a greater or lesser degree of interference as indicated in the Table 10.

Table 10. Function Coefficient.

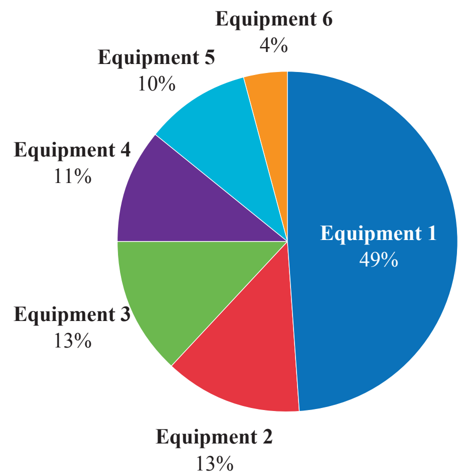
Function	Function Coefficient
Operate	1
Navigate	2

Sensitivity (S.). Multiplying the aforementioned coefficients, it was possible to obtain the calculation of the sensitivity of the assets according to the number of failures and their respective function to determine the hierarchy of the functional elements.

Once the hierarchization process for the delimitation of sensitive assets was completed, the process was based on selecting the functional elements that have a criticality value greater than 1 and that, therefore, were characterized as having a high frequency coefficient or a high coefficient of function and even both possibilities, as indicated in the Fig. 9.

Up to this point, the Investigation concentrated its efforts in organizing the existing information

Fig. 9. Sensitive assets of naval vessels.



with the purpose of generating failure statistics with the analysis of the information and without any knowledge on the naval ship, except for what is described in the historical records of failures to determine the sensitive assets described above.

For later stages, only Equipment No. 1 will be considered.

Stage 2 "FMECA"

Phase 1: Determining Components.

Methodology. In this phase, the components associated with Equipment No. 1 were studied in depth. To do this, it is necessary to rigorously review the historical data and their respective technical manuals to determine the source of equipment failures given the amount of components that resulted in each one of the assets.

Results of the Investigation.
Equipment No. 1
Out of the 793 failures recorded for this team, it was

Table 11. Sensitivity calculation.

Functional Element	No. of Faults	%	F	V	S
Equipment No. 1	793	18,04%	5	2	10
Equipment No. 2	218	4,96%	2	2	4
Equipment No. 3	209	4,75%	2	2	4

finally possible to group a total of 144 components. However, due to the large number of elements for the elaboration of the Pareto Diagram, it had to be pointed out in those 16 systems that showed a 50% of failures accumulated.

Information Analysis.
Equipment No. 1
Out of the total faults, 116 of them (equivalent to 14.63%) were related to Component 1 during the course of the 140 months, registering 38, 27 and 51 for the naval ships BN1 - BN2, and BN3 respectively.

Most of the failures were of an ordinary nature, which implies 93.1% of the events. The mentioned data is not irrelevant, since the high percentage of events linked to this asset has required a constant effort of predictive work to avoid and/or mitigate its effects in the three Units.

Phase 2: Determine failure modes and effects.

Methodology. The FMECA was the technique used at this stage to identify and list the possible failure modes that were related to the components that were individualized in each of the sensitive assets of the Units in question during the fulfillment of their operational requirement, such as for example inadequate opening of valves, short-circuit, material wear, inadequate control system, handling damage, range out of tolerance, among others, as well as the effects and/or consequences of each of these situations on the operation of the system in general.

Table 12. Types of Faults Equipment No.1.

Type of Fault	Number of Faults
Ordinary Fault	108
Faults that limits a role	5
Faults that cancel a role	3

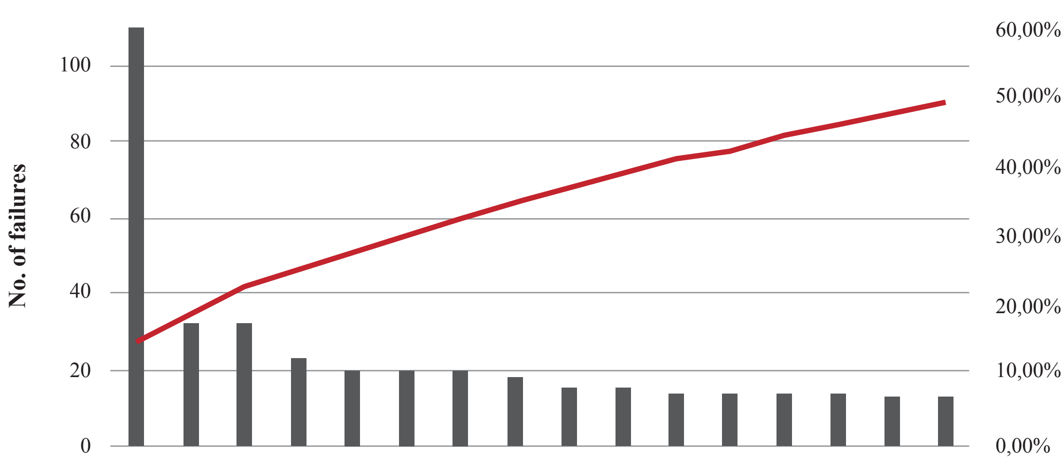
Analysis of the investigation.
Equipment No. 1
The technical details of the failure mode of Equipment No. 1 and the components involved in them can't be revealed in this report.

Phase 3: Implementation of Risk Matrix.

Methodology. To assess the risk of failures in sensitive assets, first, the sensitivity of the assets and their respective components were diagnosed, for which the risk matrix of the British Royal Navy related to the maintenance assessment defined by the Ministry of Defense was used as a basis through the standard DEF STAN 02-45 that includes the analysis of the history of the defined systems, combining two aspects:

Impact. They are referred to the consequences of failure modes. It is usual for this table to consider the dangers in personal safety, economic

Fig. 10. Pareto Diagram Equipment No. 1 .



and environmental impacts and the operational compliance of the Unit under four types of conditions: catastrophic, critical, marginal and negligible. However, for the elaboration of the matrix that was used for the sensitive assets of the naval ship under study, only the operational impact had direct incidence with this study.

Table 13. Categories of Impact.

Category	Definition	Consequences
I	Catastrophic	Loss of a platform.
II	Critical	Loss of platform availability.
III	Marginal	Systems or capacities are disabled.
IV	Negligible	Minimum risk to the mission or system

Probability of occurrence of failure modes.

Table 14. Levels of probability of failure.

Category	Definition	Consequences
A	Very High	> 1 every 1,000 hours or repeated at each exit to operate.
B	High	< 1 every 1,000 hours until an event of a year of operation.
C	Medium	> 1 every 10,000 hours more than an event in 2 years. < 1 every 10,000 hours - until an event in 2 years. > 1 every 100,000 hours more than an event in 10 years.
D	Low	< 1 every 100,000 hours until an event in 10 years > 1 every 1,000,000 more hours of an event in 100 years.
E	Very Low	< 1 every 1,000,000 hours until an event in 100 years.

The probability of occurrence of the faults was superimposed with the impacts of the failure modes (frequencies). These criteria are used to identify and compare the relative consequences of the events of critical assets through the use of this matrix. On the other hand, DEF STAN 02-45 established an associated percentage for each of the conditions, finally represented in the boxes of the table. The position of the failure mode indicates four levels of risk: high, medium, low and acceptable represented in the figure with the color red, yellow, blue and green respectively. The interpretation of this information will depend on the criticality percentage indicated in Table 15.

Fig. 11. Risk Matrix.

			Impact			
			I	II	III	IV
			Catastrophic	Critical	Marginal	Negligible
			90%	60%	40%	20%
Probability	Very High	90%	81%	54%	36%	18%
	High	70%	63%	42%	28%	14%
	Medium	50%	45%	30%	20%	10%
	Low	30%	27%	18%	12%	6%
	Very Low	20%	18%	12%	8%	4%

Table 15. Levels of Probability.

Category	Percentage
High	>30%
Medium	15-30%
Low	10-15%
Acceptable	<10%

Results of the investigation.
Equipment No. 1

Probability of risk for Team 1
Category: **HIGH** with a 42%.

Analysis of the investigation. To obtain the results of the risk matrix, it was necessary to establish certain considerations to determine the probability of occurrence of failure modes, such as the average lifespan and average hours of use of Equipment No. 1.

For both, an average of hours was calculated according to the experiences obtained from one of the three naval vessels, which were extrapolated for the rest of the Units, since they have had a similar behavior.

Stage No. 3 "Maintenance plan versus FMECA results"

Methodology. The systematic execution of the previous stages provided the opportunity to study the systems of the Department of Engineering of the naval ships by means of their respective statistics of failures. It was therefore necessary to carry out the criticality analysis from two points of view: the first to determine the sensitive assets on which the study's efforts were to be focused and the second through the results of the application of the risk matrix of the FMECA for the components whose percentages of failures predominated in the selected systems.

After having identified the functional elements, in this new phase we proceeded to distinguish the potentials and limitations of their respective maintenance plans, in order to implement a maintenance plan based on new technical criteria which arose from visits to competent technical entities, operators and maintainers specialized in the naval ship to study.

The technical consultancies were assisted by the Officers and those in charge of the relevant areas, who not only assisted in the understanding of the modes of failure of the assets, but also collaborated in proposing solutions to increase the reliability and availability of the systems.

Results of the investigation. The maintenance plan for Team 1 contemplates compliance with various tasks, which must be carried out at different time intervals, which can't be revealed in this report. In addition, it should be noted that due to the high failure rate of Component 1 of Team 1, the monitoring of this component was increased, being able to predict the moment in which it needs replacement, which does not coincide with the maintenance routine that contemplates it, that is, the replacement must be done earlier than what is programmed according to the factory maintenance plan.

Analysis of the investigation. Instead of a monitoring by condition that allows to measure Component 1 more frequently, which has been an efficient

Table 16. Guideline for determination of criticality of Equipment No. 1 [Own Elaboration].

Category	Definition	Observations
Impact	II (Critical)	It was determined that due to its operational implications, the associated impact is critical.
Probability	B (High)	There is at least 1 fault every 10,000 hours of operation, that is to say, an event every two years approximately based on the estimated calculation of the useful life and the average hours of use per year.

measure in order to carry out a predictive maintenance of the failure, it is necessary to implement solutions that are effective to increase the life useful for this component. Since, while the failure is being constantly monitored and, therefore, thanks to this measure is an event controlled by its maintainers, it is still necessary to replace it before its maintenance plan.

Conclusions

1. Reliability Engineering is the procedure that, through analytical tools, provides an opportunity to implement improvements both in management areas and in the maintenance plans of those assets with failure rates that affect the reliability and availability within a certain Organization.

2. After performing the analysis of the naval ship's fault statistics, Equipment No. 1 was identified as a sensitive asset, product of the frequency of the fault statistics and interference in the impact they produce on the functions at the moment of floating, navigating and operating in unit.

3. After comparing the original maintenance plan, based on the recommendations of the manufacturers, with the results obtained from the FMECA analysis, improvements were proposed in the incorporation of maintenance tasks for Equipment 1, which can't be detailed in the present report.

Bibliographic references

ARATA, A. & ARATA, A. (2013). *Ingeniería de la Confiabilidad. Teoría y aplicación en proyectos de capital y en la operación de instalaciones industriales a través del enfoque R-MES.* Chile: Ril Editores.

BONNEL, R. Y BOWELS, J. (1998). *Failure Mode, Effects and Critically Analysis*. Simposium Anual de Confiabilidad y Mantenibilidad. Estados Unidos.

Consultoría de Proceso. Análisis de Causa Raíz. Recuperado: 22 de junio de 2016, de: http://www.consultoriadeproceso.com.mx/causaraiz.html

DURÁN, J. (2012). *Gestión de Mantenimiento bajo estándares internacionales como PAS 55 Asset Managment*. Recuperado el 9 de abril de 2016, de: http://www.mantenimientomundial.com/sites/mm/notas/PAS55.pdf.

ESPINOZA, F. (2013). *Confiabilidad operacional de equipos: metodología y herramientas*. Chile: Universidad de Talca. Recuperado el 11 de febrero de 2016, de:http://docplayer.es/6350864-Confiabilidad-operacional-de-equipos-metodologias-y-herramientas.html.

GARCÍA GARRIDO, S. (2015). *Ingeniería del Mantenimiento*. Volumen I y II. España: Renovotec Editorial.

MESA, D., ORTIZ, Y. & PINZÓN, M. (2006). *La confiabilidad, disponibilidad y mantenibilidad, disciplinas modernas aplicadas al mantenimiento*. Volumen XII, p. 155 -160. Colombia: Scentia Et Technica.

MOUBRAY, J. (2004). *Mantenimiento centrado en la confiabilidad*. Estados Unidos: Industrial Press Inc.

MUÑOZ, M. (2009). *Mantenimiento Industrial*. España: Universidad Carlos III de Madrid. Área de Inge-niería Mecánica.

REYES, P. (2007). *Análisis del modo y efecto de fallas (PMFEA).* Recuperado el 25 de agosto de 2016, de: http://www.icicm.com/files/PFMEA.doc.

WORDPRESS (2011). *Análisis de la fiabilidad de equipos*. Recuperado: 23 de abril de 2016, de https://sistemasmanufactura.files.wordpress.com/2011/05/sesion-22.p

Current and Potential Contribution of the Colombian Ministry of Defense to the National River Master Plan and the Accomplishment of the Sustainable Development Goals through COTECMAR

Aporte Actual y Potencial del Ministerio de Defensa de Colombia a través de COTECMAR al Plan Maestro Fluvial y el Cumplimiento de los ODS

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Abstract

This article aims to present the current and potential contributions made by the Ministry of National Defense through the Corporation of Science and Technology for the Development of the Naval Maritime and River Industry - COTECMAR - and the National Navy to the River Master Plan and to the fulfillment of the Sustainable Development Objectives defined in the United Nations Agenda 2030. To this end, the contributions that have been generated so far are explored, such as the case of the river piers, the pilot project for the River Information System (RIS) and the integration of the Small Vessels Committee that is essential for the operation of a future National Port Agency. Likewise, potential solutions that can operate to meet regional needs in health, education, transport, tourism, etc. are highlighted. Finally, the opportunity to integrate the ODS, the development plans and the River Master Plan in the structuring of interregional project portfolios focused on closing social gaps in Colombia is foreseen.

Key words: River Master Plan, Sustainable Development Goals, Gap, Project Portfolio.

Resumen

El presente artículo tiene como objetivo presentar los aportes actuales y potenciales realizados por parte de Ministerio de Defensa Nacional a través de la Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval Marítima y Fluvial – COTECMAR - y la Armada Nacional al Plan Maestro Fluvial y al cumplimiento de los Objetivos de Desarrollo Sostenible definidos en la Agenda 2030 de las Naciones Unidas. Para esto son explorados las contribuciones que hasta ahora han sido generadas, como el caso de los embarcaderos fluviales, el proyecto piloto para el Sistema de Información Fluvial (SIF) y la integración del Comité de Pequeñas Embarcaciones que resulta esencial para la operación de una futura Agencia Nacional de Puertos. Igualmente se destacan soluciones potenciales que pueden operar para atender necesidades regionales en temas de salud, educación, transporte, turismo, etc. Finalmente se vislumbra la oportunidad para integrar los ODS, los planes de desarrollo y el Plan Maestro Fluvial en la estructuración de portafolios de proyectos interregionales enfocados en el cierre de brechas sociales en Colombia.

Palabras claves: Plan Maestro Fluvial, Objetivos de Desarrollo Sostenible, Brechas, Portafolio de Proyectos.

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Introduction

The Ministry of National Defense, based on its Strategic Plan for the Defense and Security Sector 2016-2018,[1] is in a process of adaptation to the country's needs in the post-conflict period. This tool has been built under the guidelines of the National Development Plan (PND) 2014-2018 "All for a new country". This is[2] based on the development of three pillars: Peace, Equity and Education, as well as six cross-cutting themes: 1) Competitiveness and strategic infrastructure, 2) Social mobility, 3) Transformation of the countryside, 4) Good governance, 5) Green growth and 6) Security. Based on these strategies, a governance scheme is proposed that will strengthen the presence of the state throughout the national territory and build its legitimacy "from and for the territories.

Thinking about the structuring of strategic programs to close the gaps - country, it is important to consider that the mentioned National Development Plan (2014 - 2018) became a pioneer by framing its goals within what was agreed before the United Nations with the signing of the Agenda 2030[3] where the bases and purposes of the Sustainable Development Goals are mentioned.

In this way, considering the previous historical reference, all the ministerial institutions in Colombia have adopted the bases proposed in the SDG *(United Nations, 2017)* and the NDP to contribute to closing the country's gaps. Thus, the National Ministry of Defense and its military industries, including COTECMAR, have been making significant efforts in this regard.

To frame NMD's contribution through COTECMAR in the guidelines provided by the NDP 2014-2018, Fig. 1 shows the alignment of the NDP objectives with the strategic objectives of the defense and security policy 2015-2018.

Considering this articulation of efforts (PND - PESDS[4]), taking into account that one of the objectives defined by the Ministry of National Defense is to contribute to the improvement of competitiveness and strategic infrastructure and social mobility; and highlighting the vision of the Ministry of Transport of Colombia expressed in the River Master Plan 2015[5]. This article presents the contributions that the Corporation of Science and Technology for the Development of the Naval, Maritime and River Industry - COTECMAR -, "main Center of Technological Development of the National Navy[6]" and potential advisor of the sub-directorate of Research and Development in Science and Technology of the National Agency of Navigation and Ports - ANP[7], has generated and has the potential to propose, based on the goals established in development plans, such as the "Pact for Colombia, Pact for Equality 2018-2022" which is currently being structured through citizen participation[8].

For this, it is important to consider the five components that have been identified to determine the actions that will fulfill the specific objectives of the River Master Plan 2015. Fig. 2.

Of the components highlighted in Fig. 2, this paper will only emphasize the current and potential contributions to a) River and Connection Infrastructure, b) Operation, c) promotion and institution.

Contributions to the components of the River Master Plan

In view of the new political-military scenario in Colombia and the process of adaptation to the

[1] (Ministry of National Defense - Colombia, 2016).
[2] (National Planning Department - DNP, 2015).
[3] Signed at the United Nations headquarters (New York) on 27 September 2015 by 193 countries that agreed on commitments to sustainable development.

[4] Strategic Plan for the Defence and Security Sector.
[5] Developed by the Ministry of Transport of Colombia, the National Planning Department (DNP), ARCADIS and JESYCA S.A.S, determines the vision of the country in the search for a more competitive, clean, safe and social river transport.
[6] According to the Naval Strategic Plan 2015 -2018 (Colombian National Navy, 2016).
[7] According to the River Master Plan 2015, ANP is the Agency that is projected to create for the institutional and centralizing order of the functions and responsibilities that are disintegrated in different entities that today try to attend the river transport system.
[8] As can be seen in the platform https://www.pactoporcolombia.gov.co/pnd, created by the current national government, for citizen participation in the construction of the new National Development Plan.

Fig. 1. Alignment of NDP objectives with the Security and Defense Strategy - Source (Ministry of National Defense - Colombia, 2016).

Transversal Strategy NDP	NDP Objectives	NDP Strategic guidelines	NDP Actions	Objectives of the defense and security policy "all for a new country"
Security, justice and democracy for the construction of peace	Promote security and defense in the national territory	Modernize and strengthen security and defense institutions	Human capital	Objective 06: Continuously transform and modernize the Defense Sector, as well as improving education, welfare, morale and safety legal as well as financial management, budgetary and contractual force Public
			Capabilities planning	
			Sustainability and efficiency of sector spending	
			Financial and contractual management	
			Human rights	
			A more competitive social and business defense group (GSED)	Objective 09: Put at the service of national development, commercial, industrial and agricultural business capabilities of Defense Sector
		Contribution of the security and defense sector to the development of the country	Risk management	Objective 08: Make available to the Colombian State the capacities of the Public Force to mitigate the effects of climate change, respond to natural disasters and protect ecosystems
			Contribution to territorial consolidation	Objective 03: Contribute to the modernization of rural society linking the Defense Sector to the interventions made by the National Government for development
			Science, technology and innovation	
		Disarmament, demobilization and reintegration	Strengthening demobilization campaigns, focusing efforts on those regions where these groups concentrate their actions	Objective 01: Contribute with the capacities of the Public Force to end the conflict and peace building

Fig. 2. Components of the River Master Plan Source: Ministry of Transport, National Planning Department, ARCADIS, JESYCA S.A.S (2015).

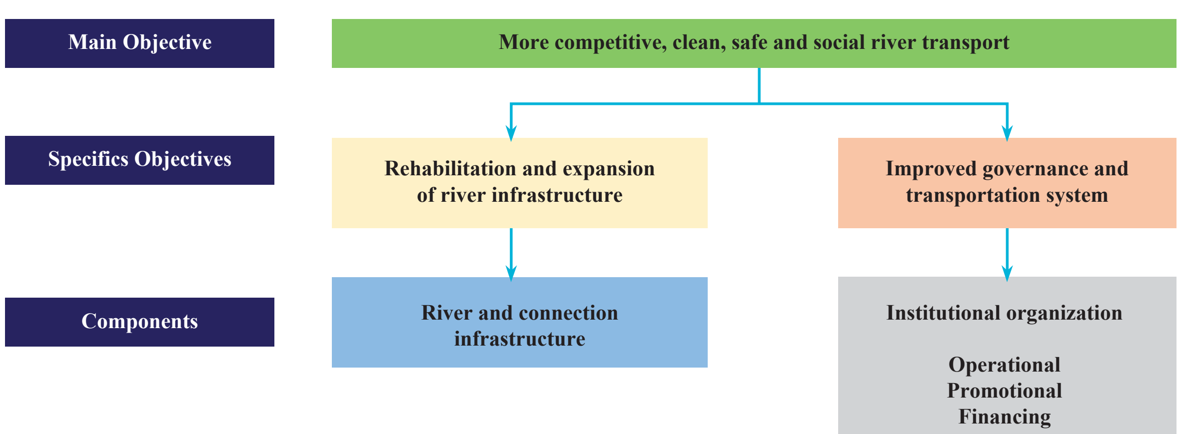
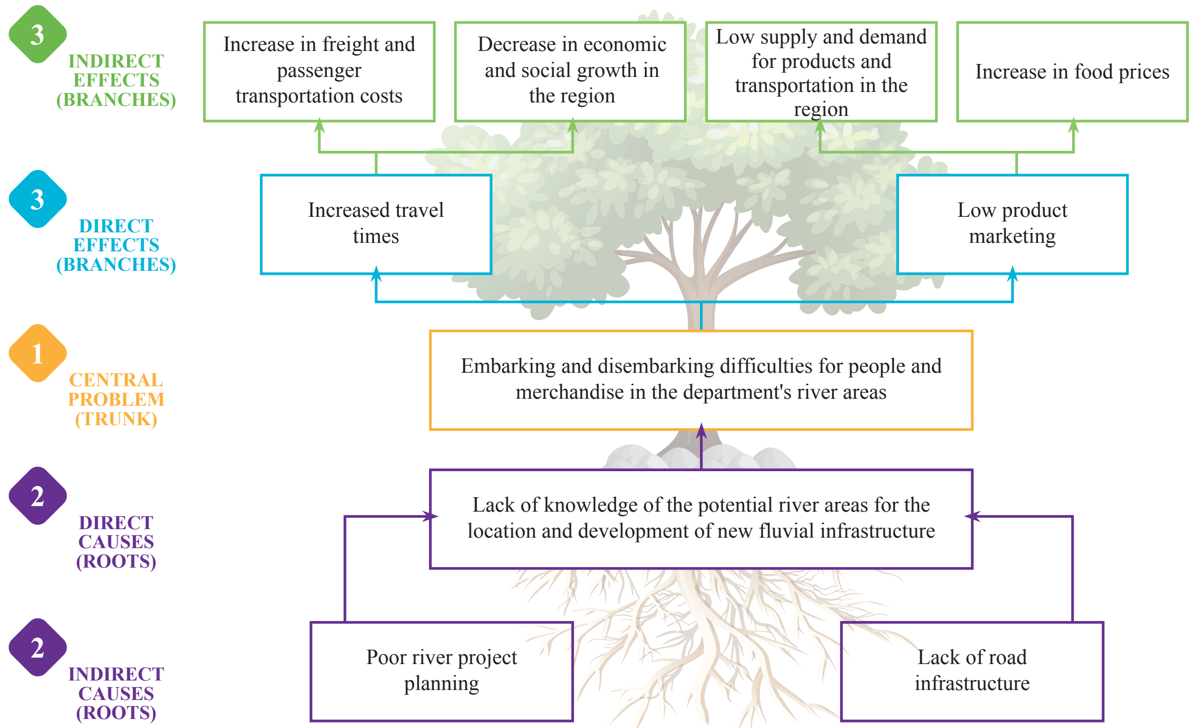


Fig. 3. Problem tree. Source: COTECMAR



country's post-conflict needs, the Military Forces play a predominant role where it is necessary to put all their capabilities at the service of the nation for the improvement of transport and river infrastructure.

This is how COTECMAR acquires special attention due to its role as a dynamizer of the naval, maritime and fluvial industry, and its contribution in the resolution of the country's challenges from its efforts in science, technology and innovation.

For this reason, the following highlights the contribution of the Ministry of Defense through COTECMAR, for the components of the River Master Plan that were previously specified.

River and Connection Infrastructure Component

This component is aimed at fulfilling two fundamental objectives: 1. Improving the projected demand for transport for cargo and passengers and 2.

For this, the Ministry of National Defense, together with COTECMAR and the National Navy, through a project focused on preliminary technical[9] studies, design, manufacture, assembly, installation and commissioning of 12 river piers in the rivers of Inírida, Vaupés, Vichada, Uva, Caquetá, Baudó, Atrato, Orinoco and Guaviare; managed to positively impact the issue of infrastructure and connection for the populations near the rivers of the mentioned regions.

This project was constituted as a solution to the identified problem (Fig. 3), formulated as:

"Difficulties in loading and unloading people and goods in the riverine areas of the departments".

The solution, river piers, with their technical characteristics (Fig. 4), such as the one delivered in the municipality of Solano - Caquetá, allowed the execution of a new study *(MDN, 2018)* for the installation of another 29 river devices in the department of Chocó, in geographical points

[9] (Ministry of National Defence, 2018).

Fig. 4. Wharf components.

COMPONENTS

1. Pontoon or modules
2. Gate or walkway
3. Railings
4. Cleats (boat mooring)
5. Simple bit (ground tie)
6. Maintenance Access
7. Defenses
8. Red signal light
9. Access steps
10. Tent
11. Manual winch

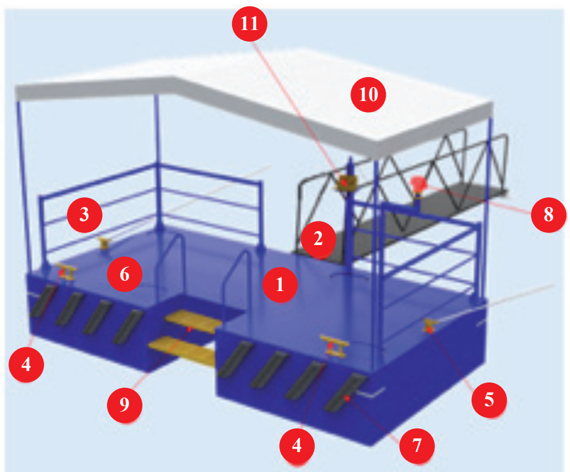


Fig. 5. Delivery of the Embarcadero - Municipality of Solano (Caquetá).

along the banks of the Atrato, San Juan and Baudó rivers.

Considering that the mentioned geographical points in the department of Chocó share the same problematic of those places in which the installation of the fluvial piers was already achieved, and taking into account the experience of the NMD and COTECMAR on the component of infrastructure and connection of the Fluvial Master Plan, it is expected to be able to take the proven solution to these riverside populations with the construction of the piers.

In addition to this, COTECMAR has envisioned other potential contributions to river development, in which the concept of modularity has become an added value for the versatility required by solutions for the use of rivers in Colombia. This has allowed the generation of multifunctional Naval Device projects with different configurations adapted to the specific needs of the riparian populations, which can be sent to any point in the country.

The following potential solutions (Fig. 6 to 12) have been designed for embarking and disembarking of passengers and cargo, river water intake and conveyance, migration control posts, military control stations, training, health posts and institutional use (registry offices, notaries, among others).

Fig. 6. Migratory River Post.

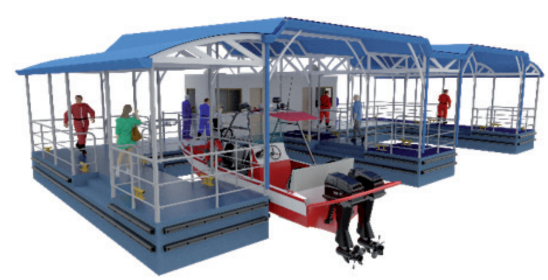


Fig. 7. Personnel and light cargo transport wharf.

Fig. 8. Water collection station.

Fig. 9. Military Area Control Floating Station.

Fig. 10. Barge for transporting vehicles.

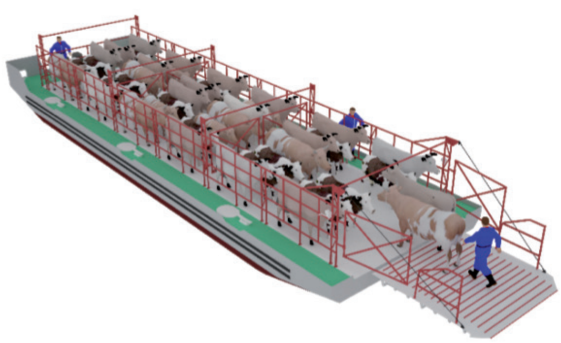


Fig. 11. Barge for transporting vehicles.

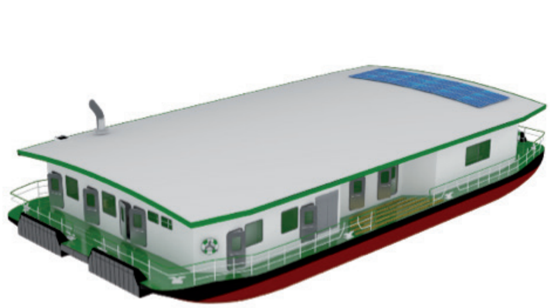
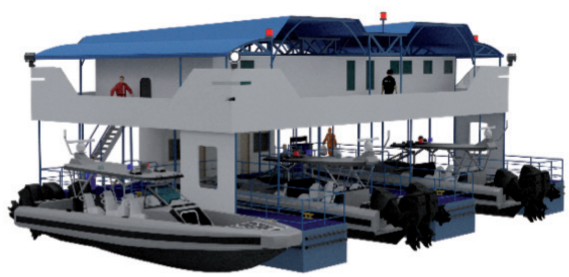


Fig. 12. River Control Station.



Component Operation

The existing and potential contribution by NMD through COTECMAR in terms of the operational component is the design, construction and maintenance of the country's river fleet, in order to provide a portfolio of solutions for the standardization and renewal of vessels that have largely passed their time of obsolescence.

The projects developed are focused on the following areas: cargo and passenger transport, health, disaster relief, tourism, social development in remote areas, environmental preservation, security of inland water bodies and education.

The figs. below, from number 13 to 24, correspond to the new products that COTECMAR can offer to promote the use and exploitation of the river arteries through the potential vessels that can operate throughout the country.

Fig. 13. River Pusher for the Magdalena River.

Fig. 14. 35-passenger boat.

Fig. 15. Logistic Support and Health boat.

Fig. 16. Ambulance boat.

Fig. 17. Rescue boat.

Fig. 18. Fireboat.

Fig. 19. Ecotourism vessel.

Fig. 20. River Barge.

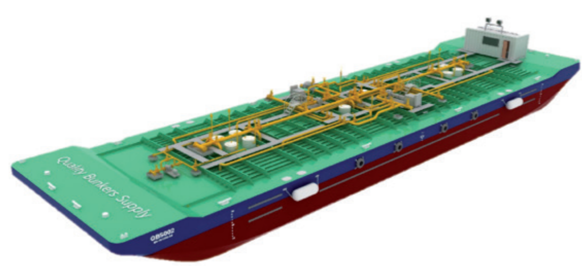


Fig. 21. Social Action Platform.

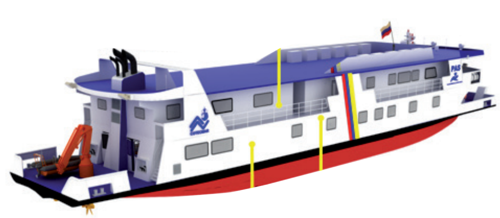


Fig. 22. Pusher and social action modules.

Fig. 23. Inter-institutional Immediate Care Center.

Fig. 24. Restaurant - bar boat.

Promotional and Institutional Component

As can be seen in the River Master Plan *(DNP, Ministry of Transport, ARCADIS, & JESYCA S.A.S, 2015)* In Colombia, river transport has not been strengthened in its operation due to duplicity and gaps in interaction by state agencies, generating difficulties in the implementation, control and policy among the entities.

The lack of academic programs specialized in water infrastructure, as well as the deficiency found in technical and economic regulation, are key factors that generate the need to revive[10] the Directorate General of Navigation and Ports through a new organizational structure as the National Ports Agency (Fig. 25) that is proposed under the River Master Plan 2015.

For this reason (structuring of the ANP[11]) and under the needs of making the Colombian Technical Standards-NTC for small vessels and disseminate the river regulations in order to create tools to this new body, is created under the leadership of the Colombian Institute of Technical Standards and Certification-ICONTEC the committee 255 of small vessels, which has as main members the Ministry of Transport, the Directorate General of Maritime, COTECMAR and Eduardoño, as technical and operational advisers provide the requirements either directly or through references to existing international standards.

At this point, it is pertinent to make a parenthesis on the Colombian Technical Standards. The NTC are created to support manufacturers, government, users, consumers, research centers, associations and professional groups, seeking to generate benefits such as:

- The removal of trade barriers.
- Facilitating technological cooperation.
- Providing unambiguous and effective communication.
- Criteria unification.
- Optimal use of resources.
- Protection of the environment.
- Consolidating the organizational experience.

For the year 2018, the ratification (see validation process in Fig. 26) of five vital norms for the standardization of small crafts, by the committee 255 has been projected (where COTECMAR is technical advisor) taking as central axis the construction of the hull and the piercing of the ships and devices destined to the fluvial operation.

[10] According to (DNP , Ministry of Transport , ARCADIS, & JESYCA S.A.S, 2015)
[11] National Ports Agency

Fig. 25. Proposed structure for the National Ports Agency.

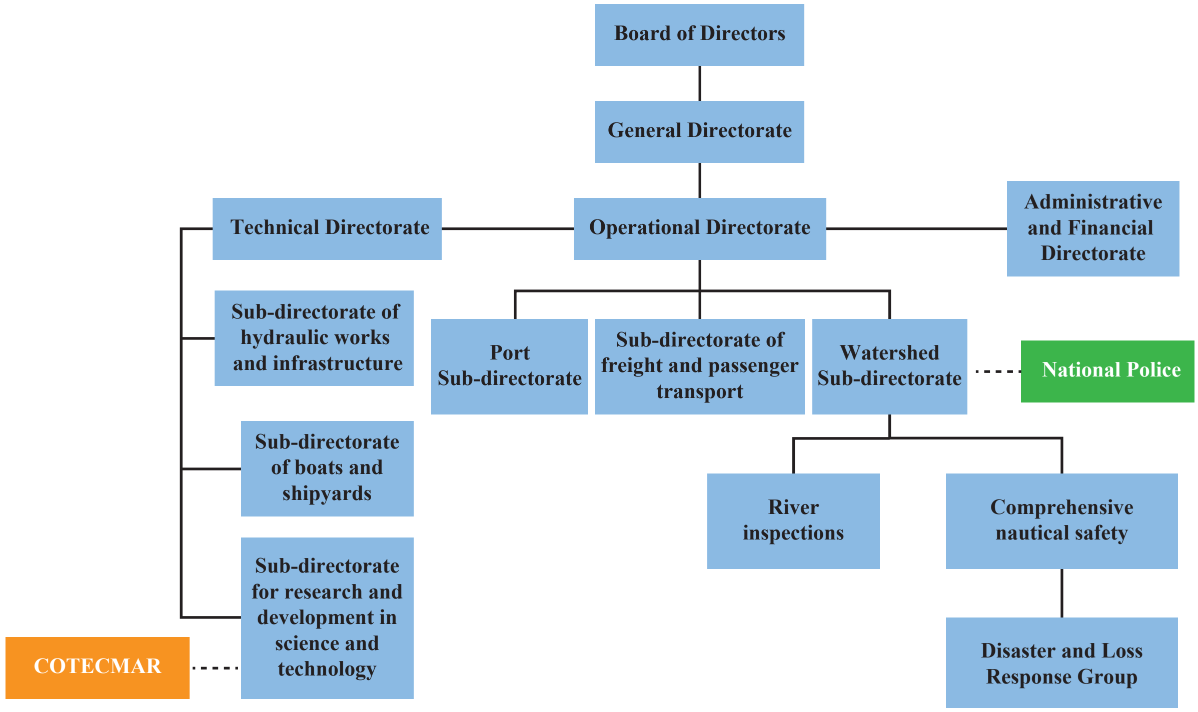


Fig. 26. Standards Validation Process - ICONTEC.

The following are the standards that are in the public consultation stage:

- Part 1 Thermosetting resins, reinforced fiber glass.

- Part 2 Core materials for sandwich construction, embedded materials
- Part 3 Materials: Steel, aluminum alloys, wood, other materials
- Part 4 Workshop and manufacturing.
- Part 5 Design stresses for fixture determination in monohulls.

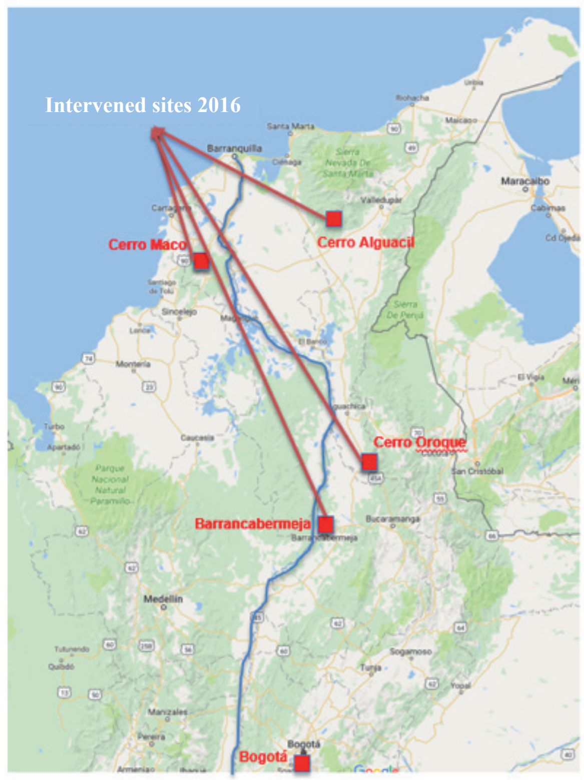
In this way, from what has been presented, it can be inferred that COTECMAR has contributed from the present in the promotional and institutional component to foment the navigability in the rivers of the country, through its participation in the "Committee of Small Boats" for the creation of norms that will become tools for the future National Agency of Ports. Likewise, in the future it is potentially projected to be an advisory body to the sub-directorate of Research, Development and Innovation for the structure proposed by[12] ARCADIS and JESYCA S.A.S in their report to the Ministry of Transport and the National Planning Department.

The River Traffic Control and Safety System - RIS

In addition to the current and potential contributions presented in the previous section, another contribution of the Ministry of National Defense to the promotion of navigability in Colombia has been made through the National Navy and COTECMAR, articulating efforts with the Ministry of Transport, to launch the initiative to create a pilot project for a River Traffic Control and Safety System on the Magdalena River in order to provide a systematic management tool capable of processing data such as basic contact information of managers and operators, water levels, river traffic information, nautical charts, among others, to regulate and control the movements of vessels on the river.

This pilot project (see Fig. 27 sites with RIS[13]) should not be considered in isolation from the country's needs, but rather as part of a program of the Ministry of Transport with the objective of developing river transport in Colombia, which includes updating regulations, the national river register[14] and structuring a bill to issue the National Code of River Traffic.

Fig. 27. Intervened sites for RIS project implementation.



With the implementation of this pilot project, the following was achieved:

- Determination of the functional requirements and elaboration of technical specifications required to satisfy the identified operational capacities.
- Definition of the configuration of the basic architecture of the system and selection of the effective technological alternative.
- Installation and testing of the system.

If the benefits of this pilot project and its functionality are analyzed, it is possible to say that this project can be framed within the contributions

[12] The National Ports Agency.
[13] River Information System.
[14] In which information will be taken to all companies.

that have been generated in the country within the Operational Component (section 2.2) that the River Master Plan contemplates, by emphasizing that the River Information System will favor the development of transport operations in a safe manner in the rivers of Colombia.

Opportunity for Gap Closure - Sustainable Development Goals

Up to this point, emphasis has been placed on the contributions that COTECMAR and the National Navy, on behalf of the Ministry of Defense, have generated for the promotion of a more competitive, clean, safe and social river transport in accordance with what is set out in the River Master Plan 2015.

The focus of this paper will be on the opportunities generated by the River Master Plan to impact the fulfillment of the Sustainable Development Goals adopted by Colombia before the United Nations, for the structuring of its Development Plan, based on the construction of interregional projects.

The River Master Plan, as indicated throughout this writing, is oriented towards the promotion of a more competitive, clean, safe and social river transport. However, if there is a good understanding of the commitments acquired by the country through the adoption of the Sustainable Development Objectives, it is possible to determine that the purpose set out in the FMP[15] is directly related to SDG 9 given that it is focused on:

a) Building resilient infrastructure.
b) Promoting inclusive and sustainable industrialization.
c) Encouraging innovation.

In this sense, and given the FMP - SDG relationship, the development of the projects and strategies proposed for the promotion of river transport in the country will have an impact on the health, transport, education and social promotion sectors, as a reflection of the fulfillment of specific goals established in the following manner:

Health sector:
- SDG 1: Ending Poverty in All Its Forms Worldwide.
- SDG 2: Ending hunger, achieving food security and improving nutrition, and promoting sustainable agriculture.
- SDG 3: Ensuring healthy living and promoting the well-being of all people at all ages.

Transport sector:
- SDG 11: Making Cities and Human Settlements Inclusive, Safe, Resilient and Sustainable.

Education Sector:
- SDG 4: Ensuring inclusive and equitable quality education and promoting learning opportunities for all.

Promotion and Development Sector:
- SDG 8: Promoting sustained, inclusive and sustainable economic growth, full and productive employment and work for all.
- SDG 12: Ensuring sustainable consumption and production patterns.
- SDG 17: Strengthening the Means of Implementation and Revitalizing the Global Partnership for Sustainable Development.

Note: *Please refer to volumes I and II of the National Development Plan 2014 - 2018 to identify the country's full SDG targets.*

In this order of ideas and under the premise that investment in infrastructure and innovation are fundamental engines for economic growth, to achieve the revitalization of river navigability in Colombia it is necessary to articulate the needs that have been diagnosed in development plans at the national and departmental level with potential projects that will generate solutions focused on closing gaps.

Therefore, to achieve this articulation, we propose to use the methodological proposal developed

[15] River Master Plan.

in the Science, Technology and Innovation Management (GECTI) of COTECMAR, which aims to identify portfolios of interregional projects for economic development and the use of the river aptitude in Colombia *(Murcia, Salgado , Gil, Saravia, & Ortega , 2018)*.

In this way, it will be possible to understand the nation's strategy, identify existing territorial needs, categorize, evaluate and select them in order to prioritize potential projects and finally submit for approval by the sponsors (departmental governors, for example) the various initiatives (such as those presented in section 2) that COTECMAR and the National Navy can offer to promote navigability by obtaining resources that need to be allocated to strengthen the infrastructure, connection, operation, promotion and institution components of the River Master Plan, impacting the country's goals as contemplated in the National Development Plan.

Conclusions

This work focused on showing the importance for State entities to assimilate and understand what is contemplated within the River Master Plan 2015, in order to promote the bases of a more competitive, clean, safe and beneficial river transport system for the social development of the country.

Likewise, emphasis was placed on the role that the Ministry of National Defense has played, with the National Navy and COTECMAR as the main references of this institution, in promoting navigability and generating potential proposals to close existing gaps in infrastructure, transport, health, education and social promotion, among others, in the country's coastal regions, hand in hand with the efforts made by the Ministry of Transport.

Within the different components that the River Master Plan has for the fulfillment of its main objectives (rehabilitate the river infrastructure and improve the governance of the transport system) this article explored the present contributions that the National Navy and COTECMAR have generated to dynamize the river development, exposing the case of the river piers, the River Information System (RIS) and the integration of the "Small Boats Committee".) Likewise, the potential contributions that these entities can make to the operational component were presented, based on the presentation of projects (multifunctional vessels) to address current problems. The contribution that can be made in Science, Technology and Innovation if the National Port Agency is structured was also highlighted.

Finally, the importance of articulating the National Development Plan, framed within the commitments acquired before the United Nations to comply with the Agenda 2030 for Sustainable Development, with all the other plans and strategies that the National Government draws up at the different ministerial levels (such as the River Master Plan) to close social gaps, was also highlighted. To this end, a methodological proposal used to structure interregional project portfolios to allow the different regions to allocate resources to solve common problems that slow down their economic growth is recommended.

Bibliography

ARMADA NACIONAL DE COLOMBIA. (2016). *Plan Estratégico Naval 2015 - 2016*. Bogotá.

DEPARTAMENTO NACIONAL DE PLANEACIÓN - DNP. (2015). *Plan Nacional de Desarrollo 2014 - 2018, Todos por un Nuevo País. Tomo I y Tomo II*. Bogotá: Imprenta Nacional de Colombia.

DNP , Ministerio de Transporte , ARCADIS, & JESYCA S.A.S. (2015). *Plan Maestro Fluvial*. Bogota.

MINISTERIO DE DEFENSA NACIONAL. (2018). *Contrato Interadministrativo No 0032-ARC-CBN6*. Bogota.

MINISTERIO DE DEFENSA NACIONAL -

Colombia. (2016). *Plan Estratégico del Sector Defensa y Seguridad - Guía del Planeamiento Estratégico 2016 - 2018*. Bogotá.

MINISTERIO DE DEFENSA NACIONAL. (2018). *Contrato interadministrativo No 027-ARC-CBN6-2018*. Bogota.

MINTRANSPORTE, DNP, ARCADIS, & S.A.S, J. (2015). *Plan Maestro Fluvial*. Bogota.

MURCIA, H., SALGADO , A., GIL, C., SARAVIA, J., & ORTEGA , M. (2018). Methodological Proposal for the Identification of an Interregional Project Portfolio for the Economic Development and Exploitation of Riverine Vocation of Colombia. *Ship Science and Technology*, 63-72.

NACIONES UNIDAS. (2017). *Anexo: Marco de Indicadores Mundiales para los Objetivos de Desarrollo Sostenible y Metas de la Agenda 2030 para el Desarrollo Sostenible*. Naciones Unidas.

Calculation of the Specific Attenuation in Satellite Bands Due to the Rain in the City of Cartagena and its Importance in the Naval Field

Cálculo de la Atenuación Específica en Bandas Satelitales Debida a la Lluvia en la Ciudad de Cartagena y su Importancia en el Ámbito Naval

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Abstract

This work studies the attenuation by rain that occurs in the Caribbean region, specifically, in high frequency bands, considering that modern communication systems make greater use of satellite bands. In this sense, the methodology of the recommendation ITU 838 was used to calculate the radio attenuation by rain in the city of Cartagena (Colombia), for the range of 1-100 GHz, and the data provided by the Center of Oceanographic and Hydrographic Research - CIOH were used as atmospheric information sources. As a result, the attenuation for the first quarter of the analyzed years was observed to be low (2.0x10-2 dB/km), growing in the following months until October (1.0x10-1 dB/km), when it decreases again. This information is particularly useful in the naval field, especially, in relation to the use of these frequencies for information exchange.

Key words: Rain attenuation, rain rate, satellite communications.

Resumen

En este trabajo se estudia la atenuación por lluvia que se presenta en la región Caribe, específicamente, en bandas de alta frecuencia, considerando que los sistemas de comunicación modernos hacen mayor uso de las bandas satelitales. En este sentido, se empleó la metodología de la recomendación UIT 838 para calcular la radioatenuación por lluvia en la ciudad de Cartagena (Colombia), para el rango de 1-100 GHz, y se emplearon como fuentes de información atmosférica los datos provistos por el Centro de Investigaciones Oceanográficas e Hidrográficas – CIOH. Como resultado, se observó que la atenuación para el primer trimestre de los años analizados es baja (2.0x10-2 dB/km), y crece en los meses posteriores hasta llegar a octubre (1.0x10-1 dB/km), cuando vuelve a presentar una disminución. Esta información resulta de gran utilidad en el ámbito naval, especialmente, en lo relacionado con el uso de estas frecuencias para el intercambio de información.

Palabras claves: Atenuación por lluvia, ratio de lluvia, comunicaciones satelitales.

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Introduction

When aiming to establish communication between two very distant points or when one of them is moving (ships, helicopters, airplanes, etc.), it is most convenient to use a wireless medium, such as radio signals. These signals are defined as electromagnetic waves, with an electric and a magnetic component, which when propagated through the atmosphere, present the phenomena of refraction, reflection, dispersion and diffraction [1], when the wave front goes through an obstacle. Almost all the links made are propagated in the troposphere, a layer in which meteorological phenomena such as snow, hail, fog, clouds and rain occur. Among these, rain is the main cause of attenuation for high frequency signals [2].

In recent years, there has been an increase in the use of satellite communications systems; In the specific case of Colombia, for example, in July 2018 the Colombian Air Force (FAC) was scheduled to launch a satellite in low earth orbit (LEO) with the purpose of providing security to the country by capturing images with enough resolution to detect illicit crops, forest fires, illegal mining, as well as to evaluate water resources and prevent their extinction, among other security activities for the country [3].

However, this boom in the use of communication systems poses a series of challenges, one of which is the attenuation caused by rain when working at frequencies on the order of gigahertz [4]. Rain causes signals to be attenuated because water drops absorb the energy and, sometimes, cause signal energy to be dispersed [2], resulting, in some cases, in the link not being available for a certain period. Generally, through a good design stage, there is no problem. Otherwise, two things can happen: first, the link is not available for the time required or, second, the system is over-dimensioned and achieves 100% availability at a high economic cost [5]. This attenuation phenomenon is called specific attenuation or tropospheric radio attenuation.

For this reason, in the last 13 years the Caribbean region has had a growing interest in studying how environmental conditions in the Caribbean area impact radio communications. This interest has been marked by the need to design links with guaranteed reliability. In 2007, Henríquez and Durante [6], carried out a study to obtain the radio attenuation parameter for the state of Zulia (Venezuela), calculating the tropospheric radio attenuation in dB/km for radio links and satellite systems exposed to the average rainfall of a tropical zone. The authors introduce a methodology to calculate tropospheric radio attenuation. This method consists in obtaining and conditioning the rainfall intensity values of the meteorological centers, and then applying the model provided by the ITU in recommendation P.838 [7] with which this calculation can be made. Finally, the model is applied to this monthly rainfall intensity mean (of each year) and the tropospheric radio attenuation is obtained for each month. This is the selected model to be applied in this work.

Similarly, Orozco and Durante´s work [8] aimed at predicting the specific attenuation at certain elevation angles in the city of Merida (Venezuela) for the period 2011-2014. For the four years predicted, the authors found that the variation is 0.0012 dB/km for the same month and considered that it is not significant.

In Colombia, the authors Pimienta and Durante [9] conducted a study in the department of La Guajira obtaining the levels of tropospheric attenuation of radio frequency signals due to rain. In their work, the authors concluded that from 10 GHz on, the attenuation due to rain increases considerably. Thanks to these works, the parameters being analyzed to identify the signal fading conditions in the C, Ku and Ka bands in the city of Cartagena de Indias were known, contributing to the creation of a tropospheric radio attenuation map for Colombia and facilitating the future design of links working in these frequency bands.

Since the radio attenuation in the Caribbean region, mainly in Cartagena de Indias (Colombia) is the subject of this work, the methodology of the ITU recommendation 838 [7] will be applied for its calculation and how it is affected by the frequency, rain intensity and the angle of elevation of the antenna with respect to the ground will be analyzed. This study is of particular importance for use by naval fleets in their information exchange systems, including the Colombian tactical data link Link-CO, for which the communications infrastructure available in the units afloat, operates partially in the frequency bands under study.

This article is organized as follows. Section 2 presents the methodology followed to carry out the specific attenuation calculation; then, section 3 presents the results obtained from the modeling of the information available in Matlab and Excel and, finally, the results and conclusions of the work carried out are presented in section 4.

Methodology for the calculation of specific attenuation

The methodology used to meet the objectives proposed in this work includes the following phases:

Phase 1. Identification of the model: In this phase the mathematical model provided by Recommendation ITU-R 838 was identified, with which the specific attenuation (dB/km) is subsequently calculated.

Phase 2. Data collection: In this phase, monthly rainfall intensity data (mm/month) obtained from the CIOH's serial publications was collected, organized, and conditioned. To use them in the calculations proposed in Recommendation ITU-R 838, they were transformed to a rainfall intensity rate per hour (mm/h).

Phase 3. Evaluation of specific attenuation: Once the monthly and annual averages of rainfall level are obtained, the specific attention γ_R (dB/km) is calculated considering different scenarios that allow to evaluate the interdependence between the parameters that intervene in the calculation of this factor. These parameters are: 1) operation frequency, for this case the frequencies of uplinks in the C, X, Ku and Ka bands are used; 2) polarization, considering vertical, horizontal and circular polarization; 3) elevation angle, angle with respect to the reference plane, and 4) rainfall rate, in the city of Cartagena de Indias.

Phase 4. Analysis of the results obtained (presented in graphs) and statement of conclusions relevant to the work done.

Based on the methodology described above, each phase is developed in detail below:

Phase 1. Identification of the model.

The ITU [10] [11] in the P.R838-3 standard defines the specific attenuation as follows:

$$\gamma_R = kR^{\alpha} \tag{1}$$

Equation 1, γ_R shows the specific attenuation (dB/km), where R is the rainfall intensity measured in mm/h, while k and α are constants that vary with frequency and depend on the type of polarization of the radiating antenna to be used.

The values of k and α, are calculated by [10], as follows:

$$\log_{10} k = \sum_{j=1}^{4} \left(a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j} \right)^2 \right] \right) + m_k \log_{10} f + c_k \tag{2}$$

$$\alpha = \sum_{j=1}^{5} \left(a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j} \right)^2 \right] \right) + m_\alpha \log_{10} f + c_\alpha \tag{3}$$

where f is the frequency in GHz, k can be kH or kV and α can be αH or αV. The ITU recommendation tables [10] show the values of the constants *ai, aj, bi, bj, ci, cj, ck, cα, mk* and *mα*, which are presented below:

Table 1. Coefficients for kH.

j	aj	bj	cj	mk	ck
1	–5.33980	–0.10008	1.13098	–0.18961	0.71147
2	–0.35351	1.26970	0.45400		
3	–0.23789	0.86036	0.15354		
4	–0.94158	0.64552	0.16817		

Source: ITU standard P.R838-3

Table 2. Coefficients for kV.

j	*aj*	*bj*	*cj*	*mk*	*ck*
1	–3.80595	0.56934	0.81061	–0.16398	0.63297
2	–3.44965	–0.2291	0.51059		
3	–0.39902	0.73042	0.11899		
4	0.50167	1.07319	0.27195		

Source: ITU standard P.R838-3

Table 3. Coefficients for α_H.

j	*aj*	*bj*	*cj*	m_α	c_α
1	–0.14318	1.82442	–0.55187	0.67849	–1.95537
2	0.29591	0.77564	0.19822		
3	0.32177	0.63773	0.13164		
4	–5.3761	–0.9623	1.47828		
5	16.172	–3.2998	3.43990		

Source: ITU standard P.R838-3

Table 4. Coefficients for α_V.

j	*aj*	*bj*	*cj*	m_α	c_α
1	–0.07771	2.33840	–0.76284	–0.053739	0.83433
2	0.56727	0.95545	0.54039		
3	–0.20238	1.14520	0.26809		
4	–48.2991	0.791669	0.116226		
5	48.5833	0.791459	0.116479		

Source: ITU standard P.R838-3

Phase 2. Data collection.

Considering equation 1, in order to perform the calculation of the specific attenuation γ_R (dB/km) it is essential to know the value of R (mm/h), that is, the intensity of rainfall in the region where the calculation of radio attenuation is desired. For this study, we used the data published by the CIOH [12] in its serialized journals between 2013-2020, and averaged them for each month and year. These data is presented as intensities of mm/month so it was converted to mm/h.

Table 5 shows the summary of the average monthly values of the level of rainfall in the city of Cartagena de Indias, between the years 2013 and 2020. Due to the reduced time of observation, the value of the dispersion of the data is still high. On the other hand, it can be assumed that the annual average of this rain rate has a value of 0.112 mm/h.

Phases 3 and 4 of the methodology will be described in the following section.

Calculations and analysis

The different scenarios proposed for phases 3 and 4 are shown below:

Table 5. Average monthly rainfall for Cartagena de Indias in the period 2013-2020.

Month	Average (mm/month)	Average (mm/h)	Deviation (mm/month)
January	10.955	0.030	11.225
February	5.045	0.017	3.795
March	6.234	0.020	13.447
April	9.287	0.022	10.281
May	96.254	0.134	79.060
June	85.515	0.119	56.977
July	126.876	0.176	60.382
August	74.943	0.104	28.430
September	102.585	0.142	24.124
October	213.846	0.297	92.678
November	122.298	0.170	111.458
December	67.170	0.108	74.993

Source: Own elaboration based on data taken from the CIOH [12].

Monthly variation of specific attenuation as a function of frequency

The following considerations have been considered for this study:

- Only three values: minimum, maximum, and average monthly rainfall level of Cartagena de Indias in order to observe the trend of specific attenuation behavior.
- Horizontal polarization.
- Zero elevation angle.
- Frequency range allowed by recommendation ITU-R 838, i.e, 1 GHz<f<1000 GHz.

The curve with the results obtained can be seen in Fig. 1.

With respect to specific attenuation performance, in relation to frequency variation, three well-defined zones can be seen in Fig. 1, as follows

- A first zone for frequencies below 6 GHz (f<6 GHz) where the attenuation tends to zero with values $10^{-8} < \gamma_R < 10^{-5}$ dB/km.
- Another area in the approximate range of 6 GHz <f<100 GHz where specific attenuation increases rapidly at a rate of variation of approximately 0.5 dB/km per decade.
- The last zone, over 100 GHz, a turning point appears where the specific attenuation begins to decrease with increasing frequency.

It is important to highlight the fact that, as the level of rainfall in a region increases, so does the specific attenuation.

Dependence of the specific attenuation with the polarization of the radiating antenna

The objective of this scenario is to analyze the behavior of the specific attenuation with respect to the three types of polarization available for this kind of satellite communications: horizontal, vertical and circular.

For the simulation, the annual precipitation value previously presented is required, which corresponds to R = 0.112 mm/h; in addition, an elevation angle $=\theta$ 0° is considered, and the frequency will be allowed to vary enough to contain the C, X, Ku and Ka bands. The results of this simulation can be seen in Figs. 2, 3 and 4.

Fig. 1. Monthly variation of specific attenuation as a function of frequency - Horizontal polarization.

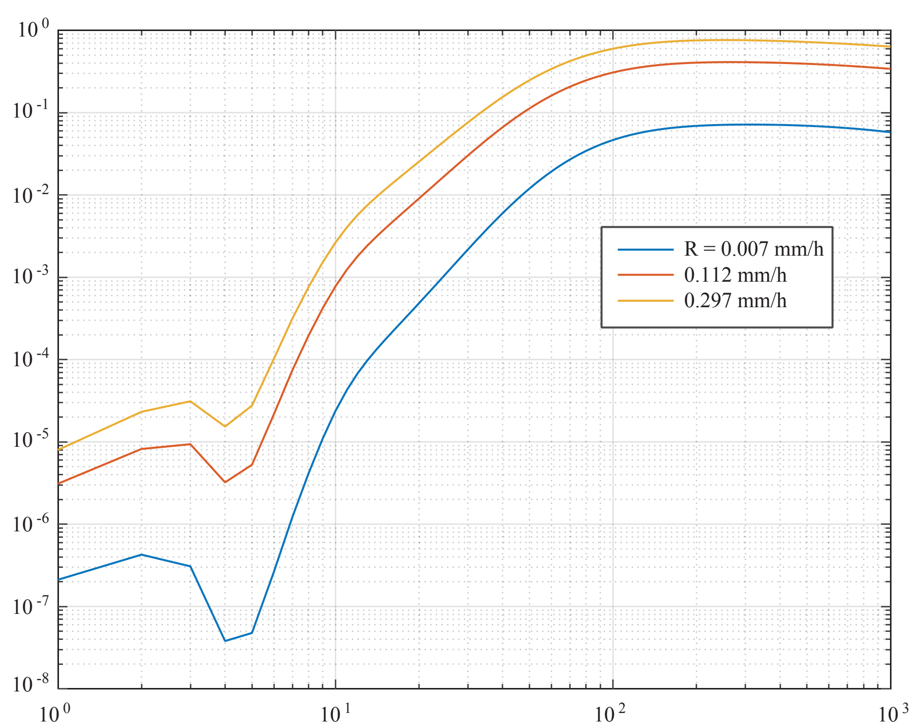


Fig. 2. Specific attenuation as a function of radiating antenna polarization. Elevation angle 0°, R = 0.112 mm/h.

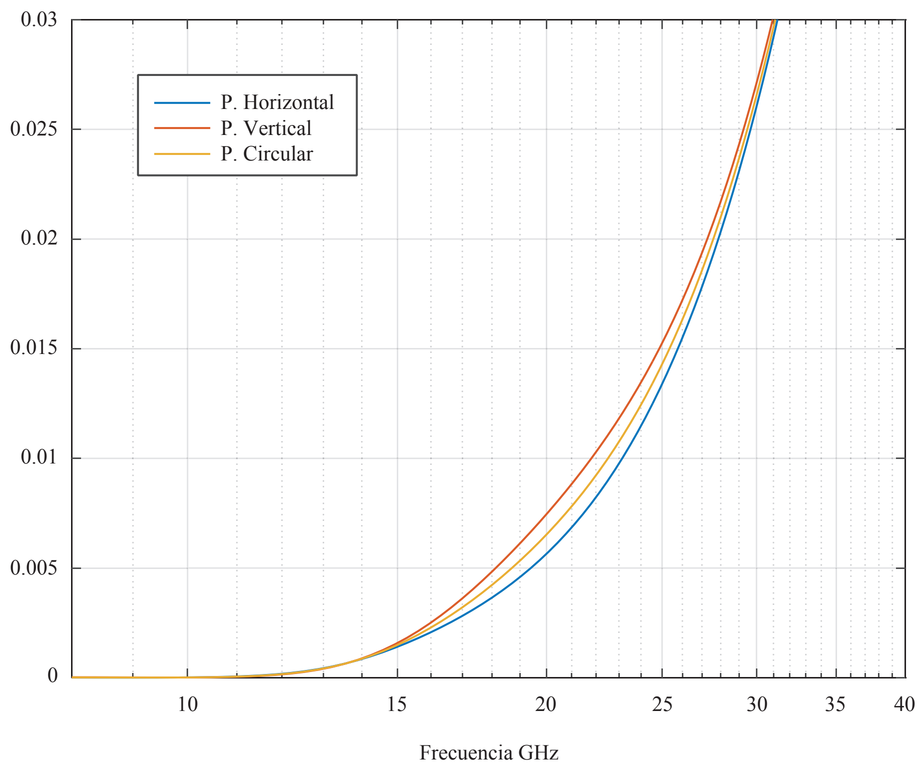


Fig. 3. Magnification of figure 2: Maximum difference between the polarizations in dB/km.

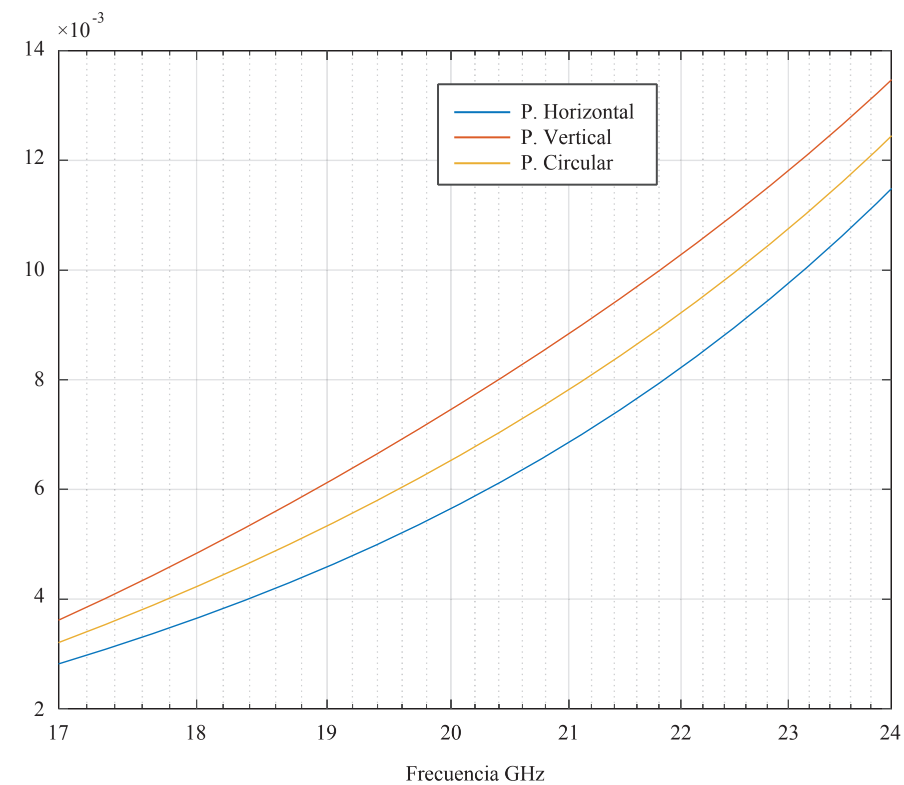
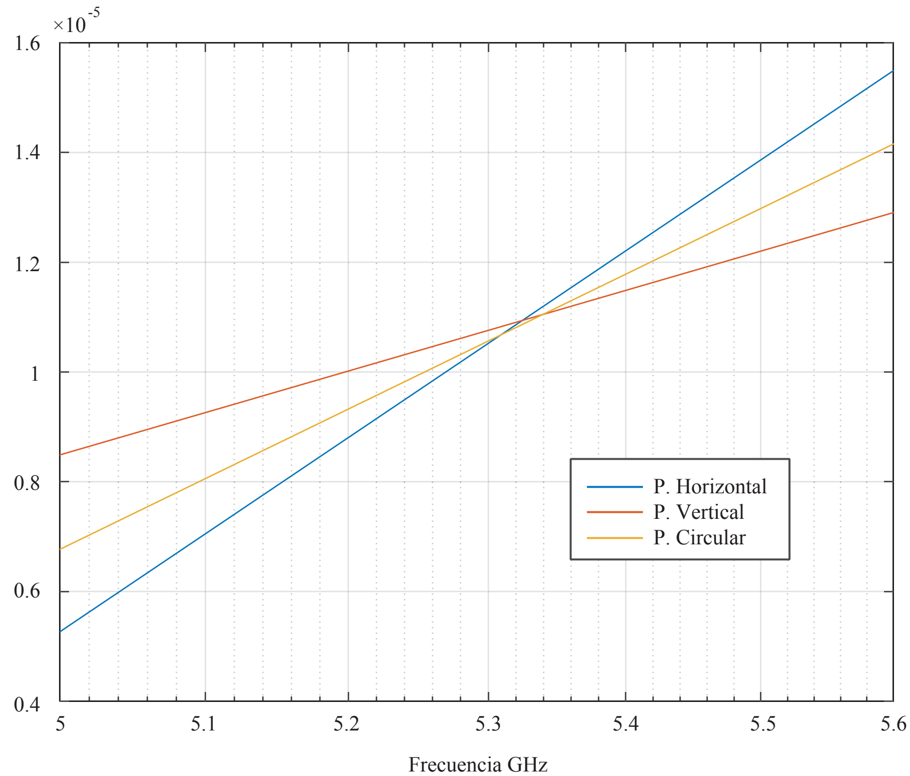


Fig. 4. Enlargement of Fig. 2: Moment when the attenuations produced by horizontal and vertical polarization are reversed.



From Fig. 2, it is possible to reaffirm what was identified in the first scenario: around the frequency of 10 GHz, the specific attenuation begins to take important values and at a high rate. However, what is new in this case, is the fact that the same thing happens for all polarizations.

The variation between the attenuations corresponding to the vertical and horizontal polarizations presented in Fig. 3 is neither constant nor uniform. For the case under study, this variation has been found to be in the range $0 < \Delta\gamma_R < 2x10^{-3}$ dB/km. In addition, the values of specific attenuation due to circular polarization are always equidistant to the values obtained in the previous polarizations, as can be seen in Figs. 3 and 4. However, whether it is possible to generalize or not is still to be proven.

Fig. 2 shows that vertical polarization produces the greatest attenuation, followed by circular and finally by horizontal polarization. However, this behavior is atypical, since the theory explained in the literature indicates that, among all of them, the one with the greatest specific attenuation is the signal emitted by horizontally polarized antennas.

In order to analyze the described behavior, attenuation coefficient graphs were made for rainfall level values greater than and less than 1 mm/h and it was found that around this value (R = 1 mm/h) attenuation changes behavior, as can be seen in Fig. 4; that is, there is a frequency in which the polarizations vary in their performance.

Dependence of the specific attenuation with the operating frequency of the system

For this scenario, the frequencies used in the satellite uplink models, in the C (6 GHz), X (8 GHz) -relevant because of its military use-, Ku (14 GHz) and Ka (30 GHz) bands were considered. In addition, an elevation angle equal to 0° and the average monthly rainfall levels presented in Table 5 were used. The results of this simulation can be seen in Fig. 5.

Fig. 5. Specific attenuation as a function of the operating frequency of the communications system. 0° elevation angle and horizontal polarization.

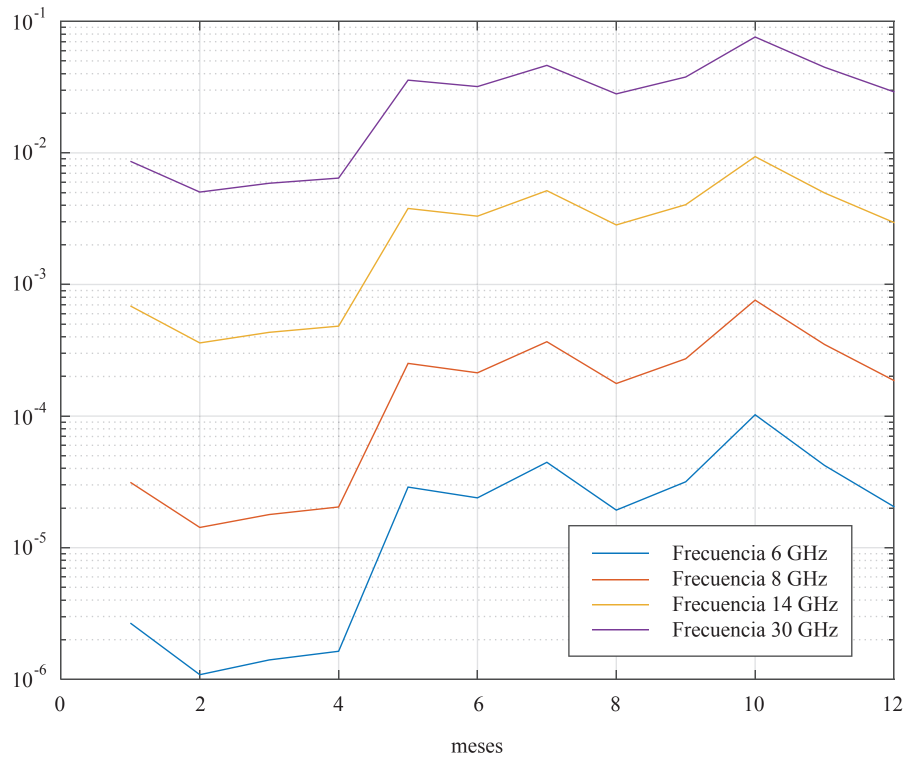


Fig. 5 identifies that the specific attenuation on the communication system will increase as the frequency does; the higher the frequency, the greater the specific attenuation.

For all the simulated cases, during the months of January to April, none of the frequencies considered exceeded the specific attenuation margin of 1.0x10-2 dB/Km.

In the case of the months between May and December, the greatest attenuation occurred in the months of July and October. The maximums recorded in the simulation are shown in Table 6, and correspond to the month of October.

Table 6. Average annual attenuation for horizontal polarization, 0° elevation angle.

Band	Frequency range (GHz)	Specific attenuation monthly average (dB/km)
C-Band	4-8	1.0x10-4
X-Band	8-12	2.0x10-2
Ku Band	12-18	3.5x10-3
Ka-band	27-40	1.0x10-1

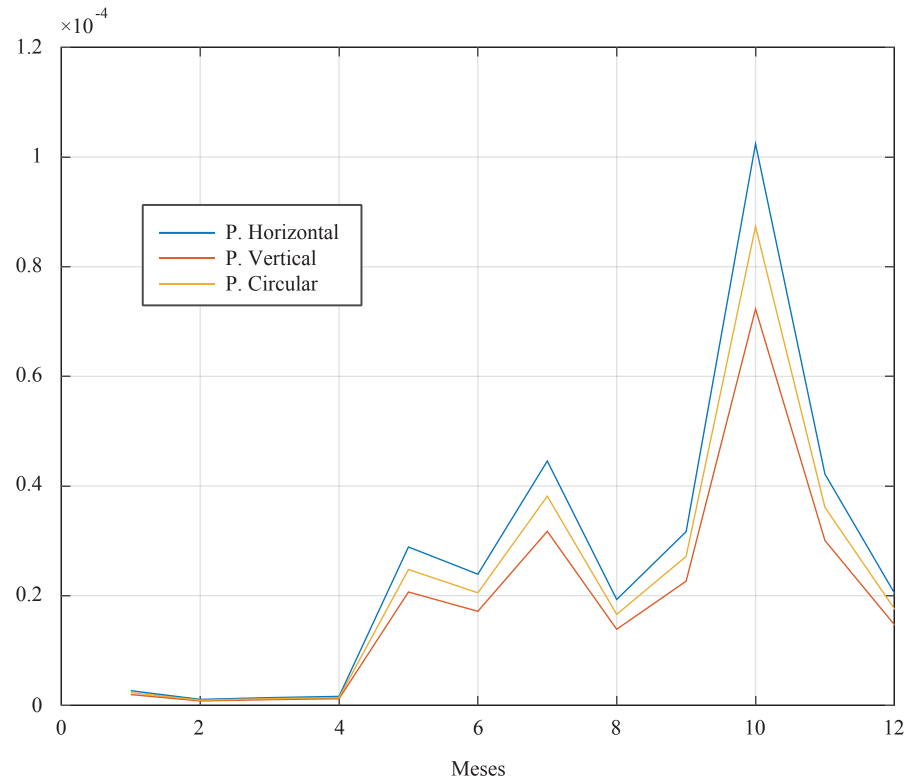
Source: own elaboration.

Dependence of the specific attenuation with the variation of the rainfall level R (mm/h)

For the implementation of this scenario, the angle of elevation was equal to 0°, the frequency was 6 GHz, and the way in which the different polarizations and variations in the level of rainfall during the months of the year in the city of Cartagena interact was studied. Fig. 6 presents graphically the results obtained.

Fig. 6 reaffirms what was described in previous sections with respect to signals coming from horizontally polarized antennas being the most affected by specific attenuation, followed in their order, by those of circular polarization and, finally, those corresponding to vertical polarization.

Fig. 6. Monthly specific attenuation for different polarizations.
For 6 GHz frequency and 0° elevation angle.



It could be observed that from January to April the specific attenuation is 0 dB/km at the frequency of 6 GHz. In addition, the two peaks of maximum attenuation occur in July with approximately 0.44x10-4 dB/km and in October with a value of 1.0x10-4 dB/km, according to what has been recorded in Table 6 for the C band.

Dependence of the specific attenuation with the elevation angle at different operating frequencies

In this section, we basically intend to analyze how increasing the elevation angle, i.e. the distance between the satellite and the transmitting station on the ground, affects the specific attenuation, considering the different working frequencies.

The simulations were carried out under the following conditions: elevation angle $0 \leq \theta \leq 90°$ The frequencies used in the satellite uplink models in the C (6 GHz), X (8 GHz), Ku (14 GHz) and Ka (30 GHz) bands, and annual average rainfall level (obtained in this work) R = 0.112 mm/h. The results are presented in Figs. 7, 8 and 9.

From what is shown in Figs. 7, 8, 9 and 10, the calculation of specific attenuations with respect to variations in the elevation angle allows us to confirm that, at higher frequencies, there are higher levels of attenuation.

As for the behavior of the specific attenuation with respect to the polarizations of the radiating antennas, the following is stated:

- For horizontal polarization, as the elevation angle increases, the specific attenuation decreases.
- For vertical polarization, as the elevation angle increases, the attenuation also increases.
- In the case of circular polarization, the specific attenuation is not affected by the variation of the elevation angle; the difference between the maximum and minimum value of the attenuation is 0.2x10-4 dB/km.

Fig. 7. Specific attenuation with respect to the angle of elevation, with horizontal polarization.

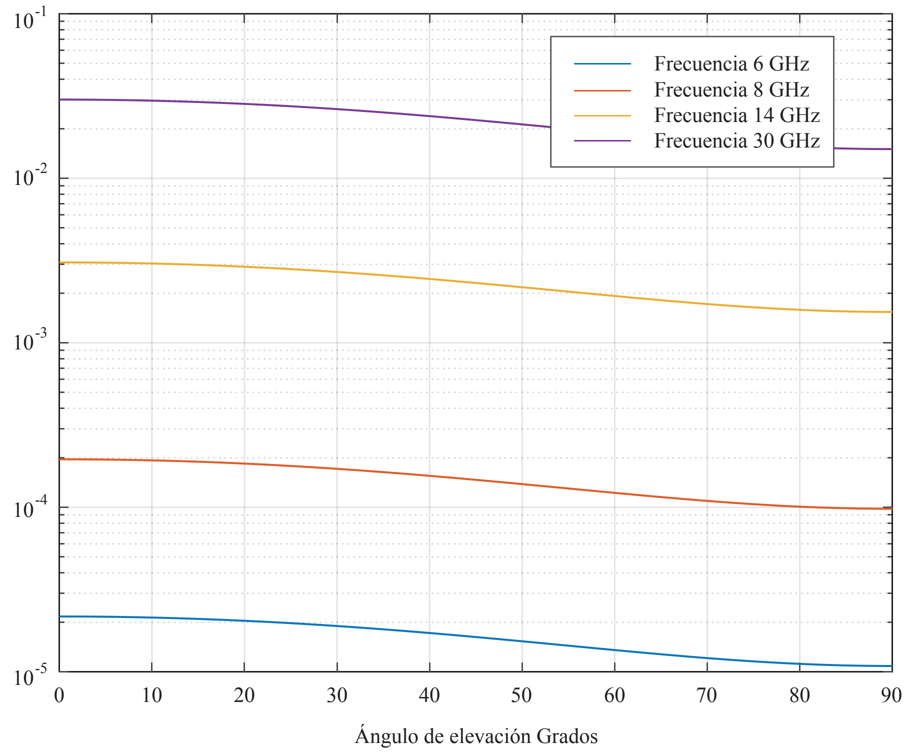


Fig. 8. Specific attenuation with respect to the angle of elevation, with circular polarization.

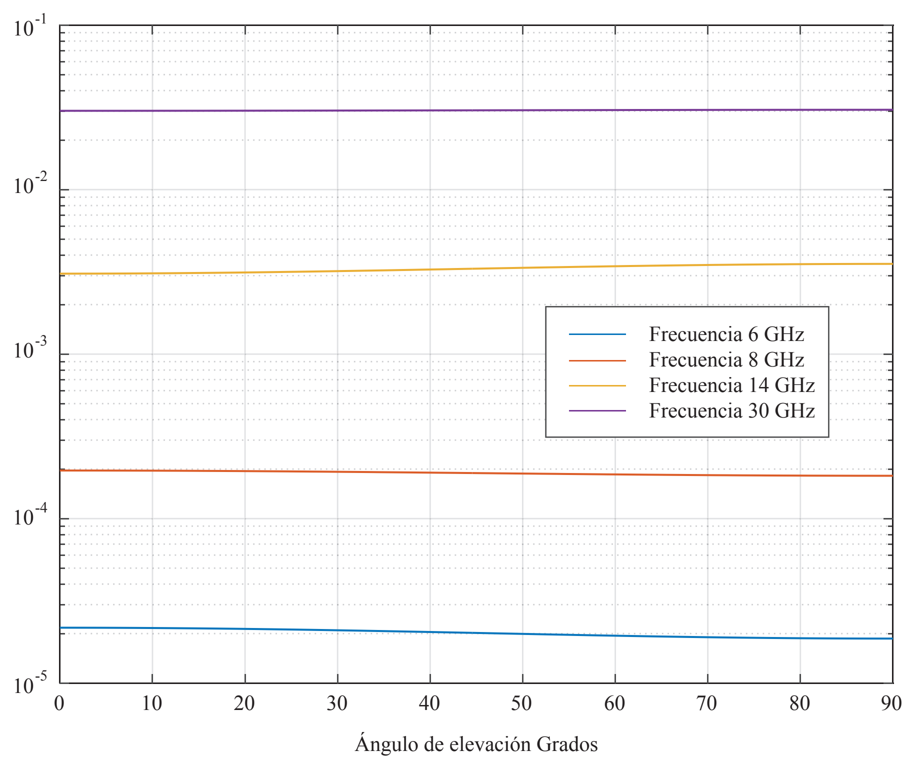


Fig. 9. Specific attenuation with respect to the angle of elevation, with vertical polarization.

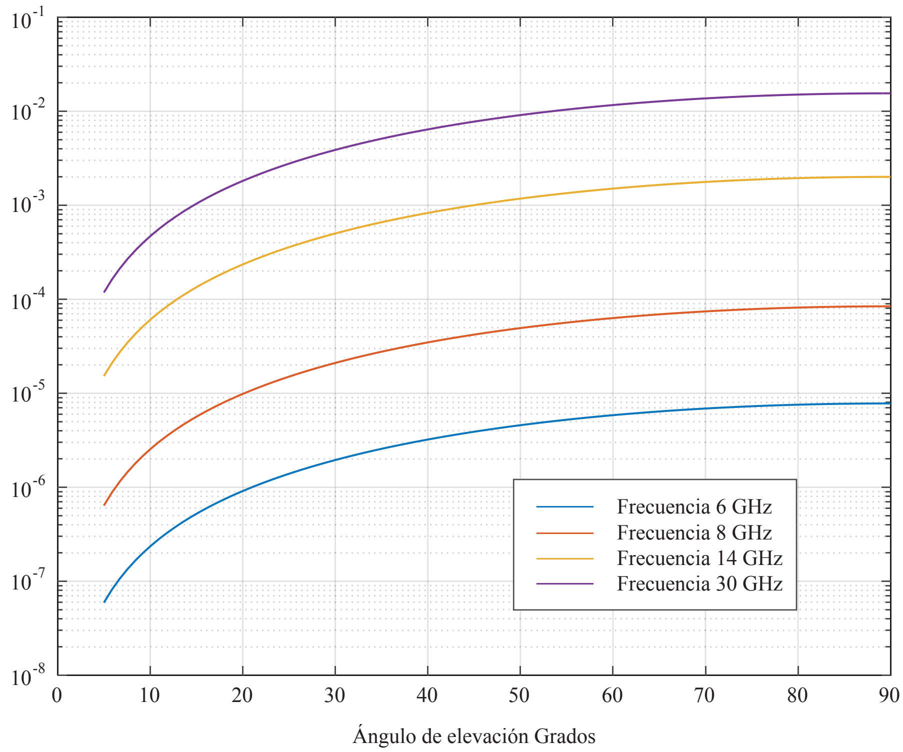
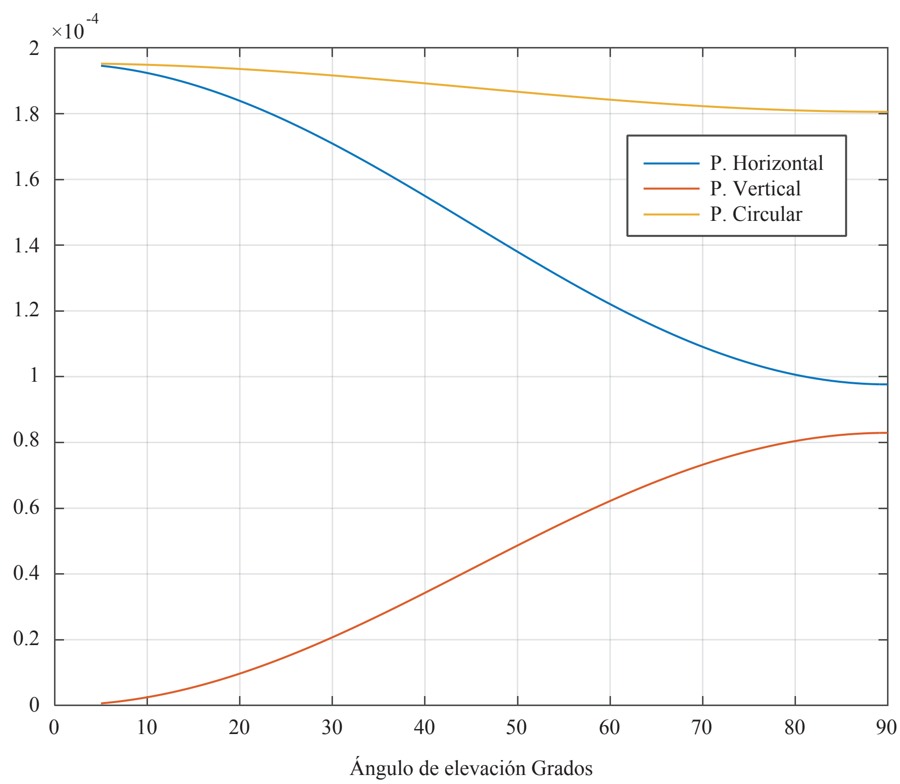


Fig. 10. Specific attenuation for different polarizations, with variation in elevation angle.



By comparing the specific attenuations according to the different polarizations and by allowing the elevation angle to vary, the greatest attenuation was found to be produced on signals with circular polarization; the least attenuation is produced on signals with vertical polarization and, finally, the signals that are intermediate in magnitude of specific attenuation are those with horizontal polarization.

Monthly variation of the specific attenuation as a function of the elevation angle

The following parameters were used in this scenario:

- The calculation of the specific attenuation is made considering the average values of the rainfall level.
- The angle of elevation is allowed to vary between 0°, 30°, 60° and 90°.
- The frequency used corresponds to 8 GHz.
- Polarization is horizontal.

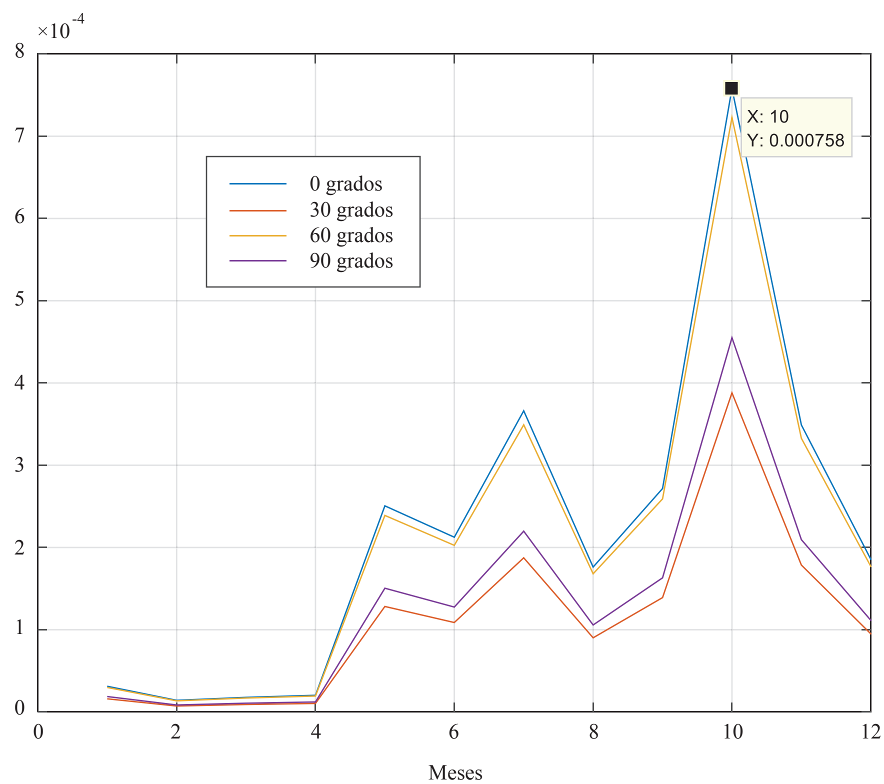
The results are shown in Fig. 11.

As already indicated in previous analyses, between January and April the specific attenuation acquires values close to zero; on the other hand, the peaks are identified in the months of July and October.

The highest attenuations occur at the 0° elevation angle, which confirms what is shown in Figure 10 for the 8 GHz frequency.

Finally, it is important to highlight that the results of this work are of high relevance in the naval communications environment, since the operators of the onboard communications systems will be able to identify how their communication will be affected, due to rain, according to the time of the year and the satellite frequency bands.

Fig. 11. Monthly variation of specific attenuation as a function of elevation angle. Horizontal polarization, frequency 8 GHz.



These calculations corroborate that, under unfavorable environmental conditions, the effectiveness of information exchange systems between naval units, in microwave bands, could be affected [13] [14], so it is particularly important to include recommendations regarding the frequency bands to be used in strategic plans for the selection of communications systems for naval units, in order to minimize the probability of signal attenuation. In this regard, it would be important to include the area of operation (for example, the Colombian Caribbean) and the time of year as input parameters.

Likewise, this work contributes to the construction of a tool that allows radio operators to identify alternate frequency bands, whose wavelengths are longer and do not present significant attenuation, especially during those periods in which rain causes considerable signal degradation. In this way, a better management of the operations will be achieved and the effectiveness of the information exchange systems will be guaranteed.

Conclusions

The methodology presented in the ITU recommendation 838 [10] was applied for the calculation of radio attenuation in links working at frequencies of 1-100 GHz. Calculations were made to obtain the average value of attenuation in each month of the year (taking data for the period 2013-2020), which showed that in the months of July and October the highest values of specific attenuation corresponding to 0.44x10-4 dB/km and 1.0x10-4 dB/km, occur respectively. On the other hand, the lowest attenuation value was presented in February with a value of 0.8x10-6 dB/km.

The behavior of the variation of the specific attenuation with respect to the frequency, reflects three well defined sectors:

- First zone. Approximately f<6 GHzthe attenuation tends to zero with values between $10^{-8} < \gamma_R < 10^{-5}$ dB/km.
- Second zone. Approximate range d 6 GHz <f<100 GHz where the specific attenuation increases rapidly at a rate of variation of approximately 0.5 dB/km per decade.
- Third zone. Over 100 GHz a turning point appears where the specific attenuation starts to decrease with increasing frequency.

This behavior is the same in the three types of polarizations (horizontal, vertical and circular) so it is concluded that, as the level of rainfall in a region increases, so does the specific attenuation.

The difference between the specific attenuations, in the different polarizations, is not constant or uniform; in the case studied, there was a maximum variation of 2.0x10-3 dB/km between the vertical and horizontal polarization. Similarly, the values of circular polarization were shown to be equidistant to those obtained with horizontal and vertical polarizations.

The order of attenuation was found to be from highest to lowest, depending on the polarization of the signal corresponds to horizontal, circular, and vertical. However, it was shown that this is fulfilled when the value of the rainfall level is greater than 1 mm/h. For values below 1 mm/h, it was shown that there are points in the graph where the polarizations reverse that order to vertical, circular and horizontal.

On the other hand, it is concluded that the specific attenuation increases as the operating frequency increases; the higher the frequency, the higher the specific attenuation.

With respect to the behavior of the specific attenuation, and considering the three analyzed polarizations, it is concluded that: 1) for horizontal polarization, as the elevation angle increases, the specific attenuation decreases; 2) for vertical polarization, as the elevation angle increases, the attenuation also increases; and 3) for circular polarization, the specific attenuation is not affected by the variation of the elevation angle, and the difference between the maximum and minimum values of the attenuation is 0.2x10-4 dB/km.

If the magnitudes of specific attenuation according to the different polarizations are compared, by allowing the elevation angle to vary, it can be concluded that the greatest attenuation is produced on signals with circular polarization, the least attenuation is produced on signals with vertical polarization, while the intermediate signal in magnitude of specific attenuation is that with horizontal polarization.

Finally, this work contributes to the construction of a tool for the radio operators of the units afloat to identify frequency bands that do not show significant attenuations during the periods in which high rainfall rates, in the Colombian Caribbean region, imply considerable signal degradation. This tool would allow a better management of communications with a positive impact on operations, ensuring the effectiveness of the information exchange systems on board.

References

[1] SALOUS, S. Radio propagation measurement and channel modelling, Chichester-England, John Wiley & Sons, 2013. 424 p. ISBN 1118502329, 9781118502327.

[2] ZUBAIR, M., HAIDER, M., KHAN, S.A. & NASSIR, J. 2011. Atmospheric influences on satellite communications. Przeglad Elektrotechniczny 87 (5), 261-264.

[3] GARVIN, M. B. Launching Latin America: International and Domestic Factors in National Space Programs. Thesis of master's degree. Naval Postgraduate School. Monterey, California, 2014-12.

[4] MANDEEP, J. S., Slant path rain attenuation comparison of prediction models for satellite applications in Malaysia, Journal of Geophysical Research. 2009, Vol. 114, pp.1-12.

[5] NANADRA, A., GOVIL, J. y KAUR, H., Optimization of satellite link design, IEEE SoutheastCon 2008, Huntsville, AL, 2008, pp. 147-152.

[6] HENRIQUEZ, L. O., DURANTE, C., 2007. Parámetro de radio atenuación troposférica por lluvia para el Estado Zulia en el rango de frecuencias de 0.4 Ghz y 60 Ghz, Télématique, Vol. 6, No. 1, pp.1–16.

[7] KESTWAL, M. Ch., JOSHI, S., GARIA, L. S., Prediction of Rain Attenuation, and Impact of Rain in Wave Propagation at Microwave Frequency for Tropical Region. International Journal of Microwave Science and Technology, 2014, Vol. 2014, pp. 1-6.

[8] OROZCO, I., DURANTE, C., 2012. Tropospheric radioattenuation forecast for different angles of elevation in the city of Mérida between 2011 and 2014. Télématique, Vol. 11, No. 1, pp.1–15.

[9] PIMIENTA, C., DURANTE, C., 2006. Niveles de atenuación troposférica en el departamento de la Guajira, Télématique, Vol. 5, No. 2, 2006, pp. 95-109.UIT

[10] Unión Internacional de Telecomunicaciones – UIT. Recomendación UIT-R P.838-3. Modelo de la atenuación específica debida a la lluvia para los métodos de predicción. 1992-1999-2003-2005.

[11] OZUOMBA, S., Kalu, C. & ONONIWU, G. 2015. Determination of the dominant fading and the effective fading for the rain zones in the ITU-R P.838-3 recommendation. European Journal of Mathematics and Computer Science. 2015, Vol. 2

[12] CIOH. CIOH - OCEANOGRAFIA OPERACIONAL. 2020. [on line]. Available: https://www.cioh.org.co/meteorologia/ResumenClimatologico.php. [Accessed: January 12, 2018]

[13] ALONGE, A. A. & AFULLO, T. J. Rainfall microstructures for microwave and millimeter

wave link budget at tropical and subtropical sites, 2013 Africon, Pointe-Aux-Piments, 2013, pp. 1-5, doi: 10.1109/AFRCON.2013.6757852.

[14] AJEWOLE, M. O., KOLAWOLE, L. B. & AJAYI, G. O., Theoretical study of the effect of different types of tropical rainfall on microwave and millimeter-wave propagation, in Radio Science, vol. 34, no. 5, pp. 1103-1124, Sept.-Oct. 1999, doi: 10.1029/1999RS900063.

[15] CARDAMA, A., Antenas, 3rd ed. Barcelona: Universidad Politécnica de Cataluña, 2009, pp. 54-55.

Design and Structural Analysis of a SWATH type vessel using the Finite Element Method and its response to Slamming events

Diseño y Análisis Estructural de un Buque tipo SWATH mediante el Método de Elementos Finitos y su respuesta en el evento de Slamming

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Abstract

The main objective of this study is to analyze the structural response of a boat during a slamming event using the Finite Element Method in a Small Water Area Twin Hull (SWATH) type boat. In the mentioned load condition, the acceptance criteria established by a classification society must be fulfilled, taking into account the areas where this event affects the structure such as the junction deck, the pontoons and other structural members established by the standard, all this generated by the high pressure loads in the ship's structure in a very short period of time being an element of study in this type of vessels, as long as they are within the range of high speed vessels. Among the main results of this study were the deformations and stresses in the structure obtained under the reference parameters of the classification society [1].

Key words: Ship, Boat, Mechanical Model, Finite Element Method, Structure, SWATH.

Resumen

El objetivo principal de este estudio, es analizar la respuesta estructural de una embarcación en el evento del Slamming utilizando el Método de Elementos Finitos en una Embarcación tipo Small Water Area Twin Hull (SWATH). En la mencionada condición de carga se deben cumplir con los criterios de aceptación establecidos por una sociedad clasificadora, teniendo en cuenta las áreas donde este evento incide en la estructura como lo es la cubierta de unión, los pontones y demás miembros estructurales establecidos por la norma, todo esto generado por las altas cargas de presión en la estructura del buque en muy corto espacio de tiempo siendo un elemento de estudio en este tipo de embarcaciones, siempre y cuando estén dentro del rango de embarcaciones de alta velocidad. Dentro de los principales resultados de este estudio se obtuvieron las deformaciones y esfuerzos en la estructura bajo los parámetros de referencia de la sociedad clasificadora [1].

Palabras claves: Buque, Embarcación, Modelo Mecánico, Método de Elementos Finitos, Estructura, SWATH.

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Introduction

The use of the Finite Element Method (hereinafter FEM) is a tool that allows to analyze and evaluate both the stresses and deformations that occurs in an element of study as a response of a load on it. This allows the Naval Design and Engineering area to perform evaluations of elements of a system, which in the case of this study, simulates the response of the structure and generates a tool for the designer to analyze the overall vessel under slamming pressures.

In this way, the aim is that the vessel to be designed complies with the requirements established in the classification regulations ensuring the structural integrity of the vessel during its life cycle in the Operation Phase. While it is true that the rules of the various classification societies are guidelines for design, these aim for the structure to support the conditions of the ocean it will face, and generates as a result the dimensions of the structural elements and all those elements that contribute to the structural integrity of the boat.

The vessel in this study was designed to comply with particular performance specifications such as speed, length and beam dimensions, for which the shapes were carried out through the use of design tools (CAD) and analysis (CAE) (Computer Aided Design- Computer Aided Engineering). This was an input in the subsequent implementation of structural analysis by the Finite Element Method with the use of numerical modeling. The process integrates the basic knowledge of surface handling and is complemented with the application of the different loads that affect the case study such as Slamming in the Wet Deck and Hull, Hydrostatic Pressure, Gravity and the Displacement of the Vessel. Within the development of this study, the mesh sensitivity analysis was carried out, which ensures the independence of the results of the mesh.

Due to the above, and in view of the fact that FEM allows the analysis of irregular geometries such as the hull of a vessel, the application of loads, the handling of the system's boundary conditions and the numerical evaluation of the materials' behavior, it can be established that it is a convenient tool to carry out the analysis of the present investigation and to observe the response of the vessel's structure.

State of the art

Currently, FEM is applied to different areas of knowledge, thus becoming a functional tool for the development of any research, validation or evaluation of a physical phenomenon. Within the applications that are most used in engineering processes, we find the analysis and evaluation that allows to determine the field of displacements, deformations, stresses in any element of the system, frequency, resistance, rigidity and fatigue among others. With which, it is possible to analyze and evaluate through a study if the conditions in which a future project can become feasible from an initial design stage and make decisions that reduce time and decrease the costs associated with an engineering design and construction process.

Based on the above and in view of the evaluation and analysis capabilities of FEM which allows to analyze the mechanical behavior in a linear, non-linear, static or dynamic way, the Naval Industry has developed the validation of its projects in the preliminary and contractual design stage with the use of these computational tools. In this way, and given the current conditions of competition in the Shipyard environment and their Design Offices, the use of FEM is a tool for the development of their activities of criteria testing and cost reduction in the Industry, with this, being able to analyze if the results obtained are acceptable against the established acceptance criteria and the products should be marketed.

An example of this application is found in the work of Numerical and Experimental Validation of Bending in a Resin Steel Sandwich Structure for bulkheads and structural members, where the real behavior is compared with the numerical one and allows according to the authors to observe the behavior curve of the material and the process of failure and subsequent cracking [4]. In the same way, in other studies observed, structures and plates of any vessel in composite material are evaluated and allow to validate the results generated by the

FEM, such as the specific case of the experimental and numerical flexion analysis of steel/resin sandwich material, which looked for to confront the real results with the FEM. The result is that both are similar and arriving at the conclusion that validates any real analysis with the numerical one for the use of Bulkheads, Reinforcements or any primary member that is required in a vessel [5]in multi-hull type boats, in [6] a trimaran-type vessel is designed, analyzed and optimized, scanned with different classification societies, the stress and deformation results are compared with each one and an overall reduction of the vessel's displacement is achieved.

Likewise, in [7] a SWATH type vessel, an analysis of the structure was carried out by means of FEM, with the purpose of comparing the response of the structure with transversal loads, as a reference in the use of numerical models that allow the evaluation of the real conditions of a vessel, demonstrating again, the viability of the use of the method.

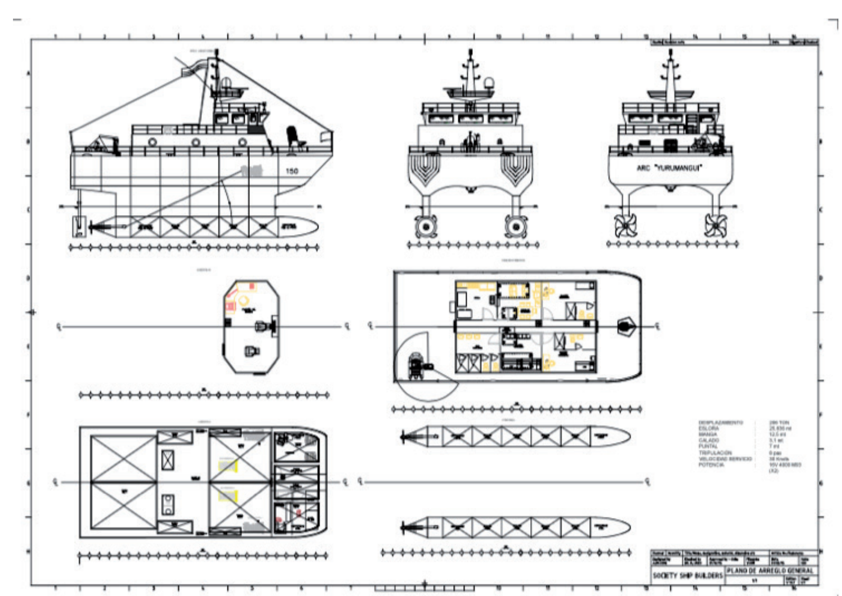
For this study understanding the conditions in which the vessel would be found was fundamental, therefore, the study of the slamming event is important in understanding that it is a transitory load that affects the structure of the vessel in its operation, evaluating this throughout its entire structure and validating the calculations enhanced in the scantlings, is a fundamental tool for any design process and testing of any vessel, allowing with it to validate that the process is suitable and responds to the objective of the present study.

This process has shown that the structure supports the stresses and deformations allowed by the classification society, under real parameters that contribute to the knowledge of a design process and structural analysis of a SWATH type vessel and gives the possibility to perform other analyses in different load conditions where it is required to study elements globally or locally using the FEM.

SWATH type boat

The vessel in this study has the general characteristics described in Table 1 and was designed as shown in the General Arrangement Plan Fig. 1, its mission profile is based on carrying out patrol operations in the Colombian Caribbean Island area, where the average wave height ranges from 1 meter to 5.56 meters according to statistics provided by the General Maritime Directorate [8] Table 1.

Fig. 1. General Arrangement Plan ARC "Yurumangui".



Source: Authors.

Table 1. Vessel characteristics.

Features	Quantity
Maximum length	26,55 m
Maximum beam	12,5 m
Design Draught	3,1 m
Strut	8 m
Service Speed	30 Kn
Distance between hulls	9,15 m
Displacement	205 ton
Installed Power	6240 Hp

The previously described design is characterized under the displacement and speed standards for high speed craft, or HSC, where it states that it cannot displace more than 243.55 tons and must have a speed greater than 17.38 knots according to equations 1 and 2 [9].

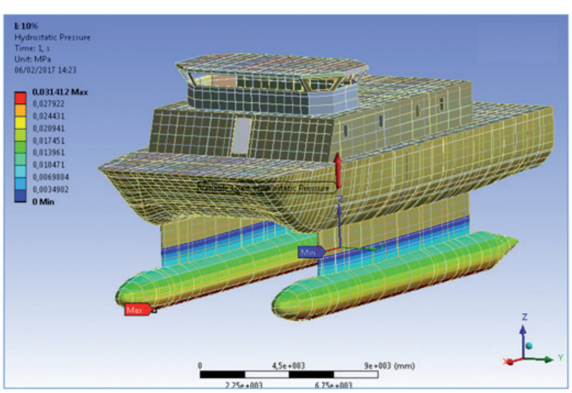
$$\Delta = (0.13 * L * B)^{1,5} \quad (1)$$

$$V = 7,16 * \Delta^{0,1667} \quad (2)$$

Loading conditions

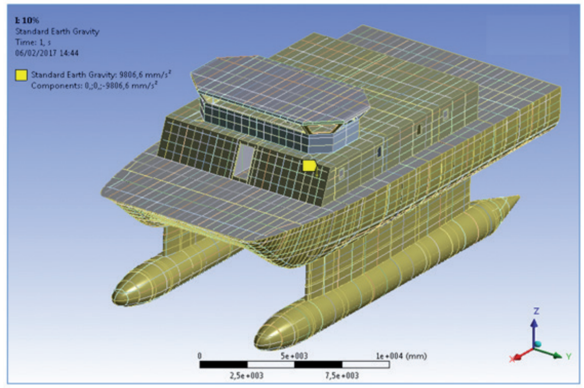
During the development of the analysis, the recommendations of the mentioned classification society were followed, for the application of the forces that act in the hull of the ship, which were divided in three different forces, characterizing the Hydrostatic Pressure with the design draught under full load (Fig. 2), the pressure during the Slamming event and the standard acceleration due to gravity, Fig. 3 [10].

Fig. 2. Hydrostatic pressure in the hull depending on the design draught.



Source: Authors.

Fig. 3. Gravity.



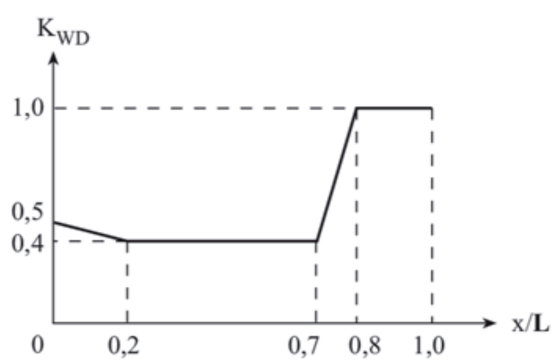
Source: Authors.

Slamming effect on the structure

In this study, the effect of slamming on the structure of the boat is analyzed. [11]This effect are the pressure loads generated by the impact of the boat with the waves in short periods. Therefore, the classification society proposes as an acceptance criterion an stress value not higher than 125 MPa [10].

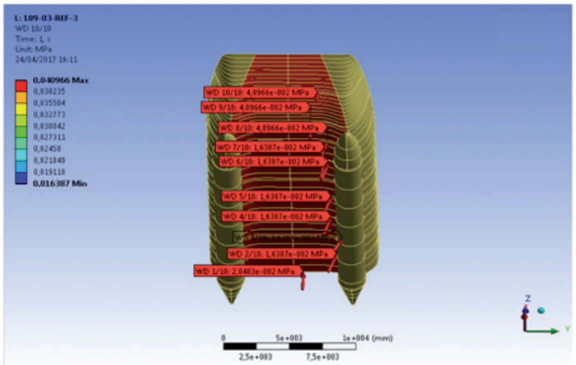
The results for the slamming load on the structure, bending moment, accelerations and others, were obtained by using the classificiation rules and construction, special vessels section 3 C 3.5.2 and C 3.5.3. of GL, which parameterize that they are a function of the dimensions of the vessel and, in the case of slamming, vary according to the length of the vessel as shown in Figs. 4 and 6.

Fig. 4. Slamming on Wet Cover.



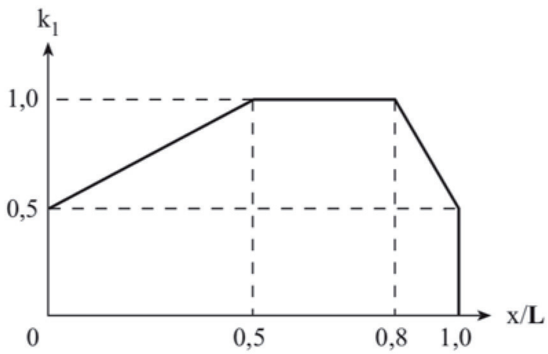
Source: Authors.

Fig. 5. Slamming Pressure on Wet Cover.



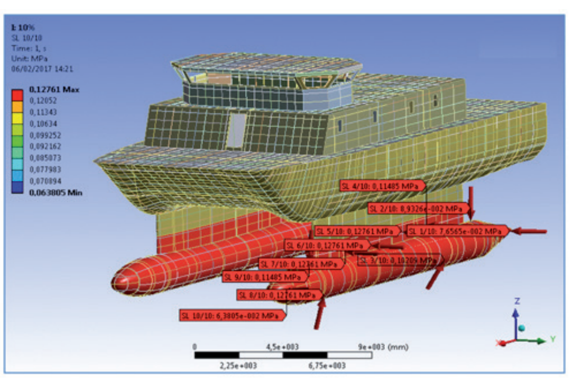
Source: Authors.

Fig. 6. Hull Slamming.



Source: Germanischer Lloyd.

Fig. 7. Slamming pressure on the submerged hull.

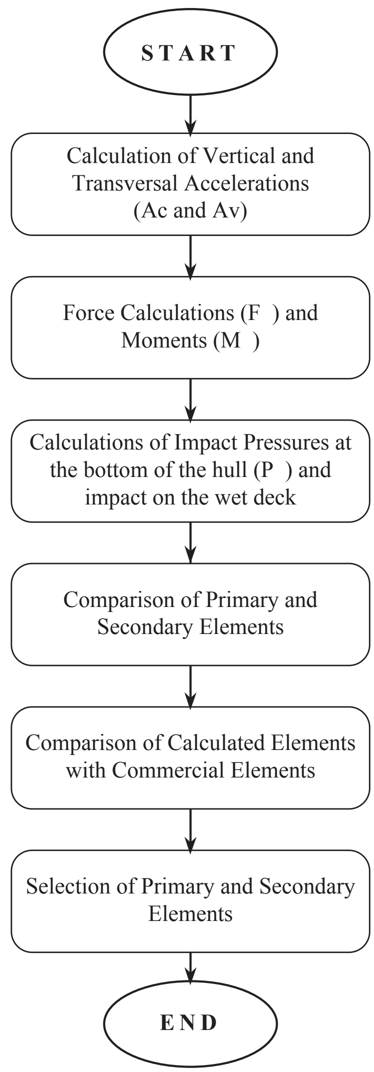


Source: Authors.

Structure of the boat

The Craft Scantling process can be seen in Figure 8 and was based on the GL classification rules, calculating the primary structural elements according to table No. 2 and Fig. 9 shows the midship section scantling drawing. For this study and for the characteristics of the patrol boat, aluminum 5083, density 2770 Kg/m^3, Modulus of Elasticity 7.1 x 1010 Pa, Poisson's coefficient of 0.33, length not supported (le) 1200 mm and a space between longitudinal reinforcements (s) of 480 mm were selected as the material and parameters.

Fig. 8. SWATH Scanning Process Flowchart.



Source: Authors.

Finite Element Model

The vessel was modeled and discretized using computer aided design software, thus modeling the hull shapes and structural elements. This process allows to materialize the project in order to export it to the finite element analysis software [12]. This allows for the analysis and observation of each of the members and their geometries so that they contribute to the structural rigidity and distribution of the loads applied to the boat [27].

Model Mesh

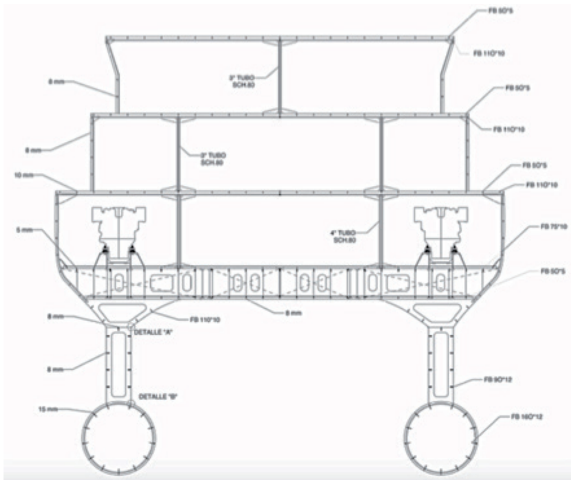
For the analysis of this structure, several factors were considered: First, the selection of the type of element, which for the case study a Shell 181 element was selected for having four nodes and six degrees of freedom and admitting normal loads to its plane, bending loads, membrane loads and moments [27]. This is a tool that can analyze the Slamming loads in the structure, and giving priority to rectangular and not triangular elements, since

Table 2. Craft Scantling.

Structural Scantling			
Plating	**Comercial (mm)**	**Calculated (mm)**	**Fraction In.**
Bottom Shell	15	11,257	9/16
Bilge Plating	8	7,388	5/16
Side Shell	8	7,388	5/16
Wet Deck	8	5,042	5/16
Internal sides	7	6,743	5/16
Deck Plating	10	9,408	1/2
Stiffeners	**cm^3**	**cm^3**	**Kind**
Bottom Stiffeners	84,00	6,53	FB 160*12
Bilge Stiffeners	26,97	2,10	FB 100*8
Side and front wall	32,38	1,26	FB 90*11
Stiffeners of the wet deck	22,21	2,10	FB 50*5
Deck Stiffeners	26,97	2,10	FB 50*5
Stiffeners of boundary	26,97	2,10	FB 50*5
Primary Supporting Members			
	cm^3	cm^3	Kind
Structure	33,601	6,534	FB 110*10
Floor	12,951	2,518	FB 75*7
Gidders	12,951	2,518	FB 75*7
Primary Supporting members of sides and	2,002	0,195	FB 50*5
Primary Supporting members of the wetdeck and internal sides of			
Wetdeck	27,672	6,534	FB 100*10
Internal Sides	33,601	6,534	FB 110*10
Primary Supporting members of decks			
Deck transverse	1,580	0,307	FB 50*5
Primary Supporting members of deckhouse	2,120	0,412	FB 50*5
Stiffeners and Girders	20,09	1,64	FB 75*10

Source: Authors.

Fig. 9. Midship section.



Source: Authors.

normal displacements in the elements can occur and cause the nodes to not represent the physics of what is happening in the system, thus generating, possibly, errors. Secondly, the aspect ratio of the elements, which should predominate in values close to 1 in symmetry and allows for evaluating the physical effects that occur in the time period (Fig. 10). And thirdly, the quality of the elements (Fig. 11). All this, allows for the generation of the appropriate mesh, resulting in better analysis results. [13].

In the process of generating the mesh, it was necessary to produce independent meshes for the structural members, which, due to their geometry, did not allow for the alignment of the nodes, thus achieving a correct distribution of the elements and allowing the analysis to be homogeneous with

Fig. 10. Aspect ratio of the elements.

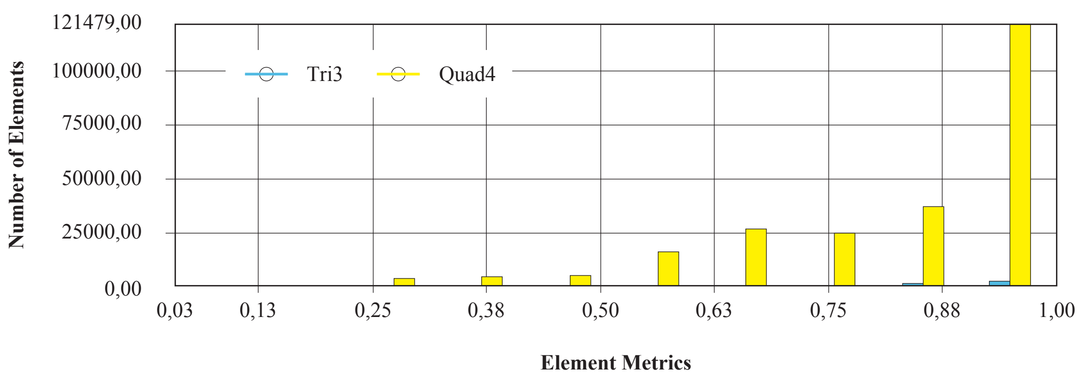
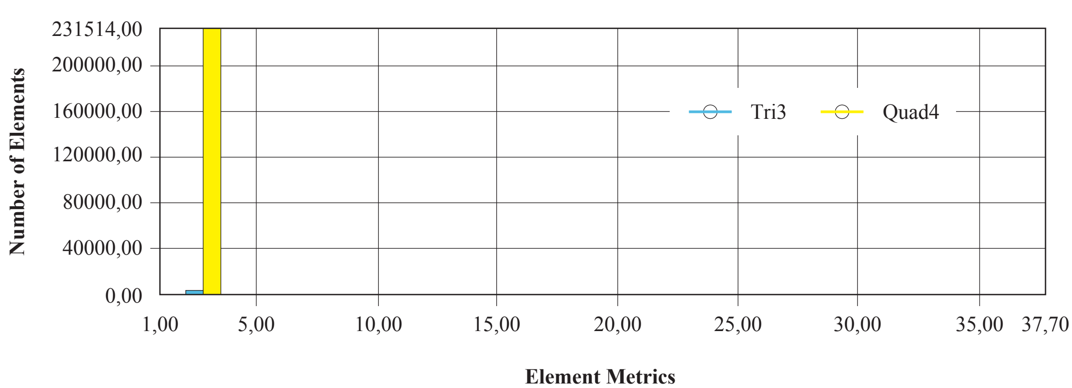


Fig. 11. Number of elements and their quality.



Source: Authors.

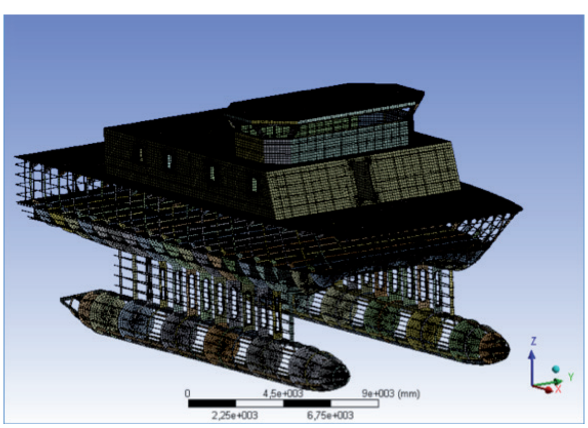
respect to the spatial distribution of the elements (Fig. 11). In order to ensure that the structure behaves as a single set, contact regions were established between the edges and faces of the different surfaces [14].

In the generation of the mesh for the analysis of the loads in the structure of the ship, different refinements to the mesh were made (Table 3) in a global way for the hull, superstructure, primary and secondary members that contribute to the structural rigidity of the ship. This is a process of global and systematic refinement of the mesh that allows to determine that the results are independent of the density of the mesh. In this iterative process, it was possible to analyze and evaluate the quality of the elements and the independence of the results with reference to the density of the same. The relation of aspect of the elements in the different meshes, and the form of the elements were verified, obtaining as a result in the finest mesh, 210,300 rectangular type elements and 1,633 triangular elements, generating a percentage of 99.29% of rectangular elements.

Mesh independecy analysis

Based on the above, the quality of the elements is deemed adequate for the structure of the study, obtaining a homogeneous mesh according to the proportions of the elements, having a density much higher than 50% (Fig. 12).

Fig. 12. Finite Element Model of the Study Vessel.



Source: Authors.

Table 3. Project Mesh Characteristics.

Number of elements		
Type	**Mesh**	**Elements**
1	Thick	164316
2	Medium	188592
3	Medium - High	208865
4	Fine	210300

Source: Authors.

In the verification of the independence of the results with respect to the density of the mesh, in Table 4, the results of stress and deformation are presented. Finally, in Table 5 the percentage of change with respect to the previous refinement is shown. The change between mesh 2 and 3 is less than 2%, which allows us to conclude that the mesh with medium-high refinement is enough to obtain satisfactory results. However, mesh No. 4 was chosen, since it does not demand excessive computational resources, giving independence to the results with respect to the mesh.

Table 4. Stress and deformation.

Number of elements		
Type	**Maximum Stress [MPa]**	**Max. deformation [mm]**
1	92,16	4,64
2	111,93	4,85
3	109,97	4,93
4	108,37	4,99

Source: Authors.

Table 5. Mesh Sensitivity Analysis.

Mesh Sensitivity Analysis		
Comparison	**% Change Stress**	**Change Deformation**
1 - 2	21,46	1,04
2 - 3	1,75	1,02
3 - 4	1,45	1,01

Source: Authors.

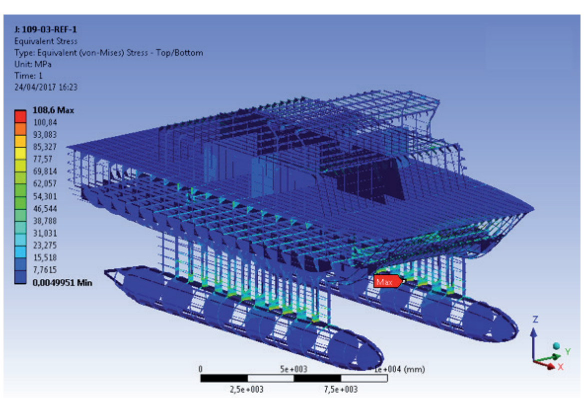
Results analysis

The physical phenomena that occur in the boat by the action of slamming load on the wet deck and hull, require a reliable result. It is necessary to evaluate the results of the stresses and deformations obtained and compare them with the acceptance criteria established by the GL classification society. As a condition for the system's contour, the inertial lightening function was used, which allows the system to be balanced, inducing fictitious loads that, for the case study, would be the Thrust Force, generating a static equilibrium [15] [16] [17].

For the GL classifier, the stress acceptance criteria should not exceed 125 MPa according to Table C 3.2.1 of the GL classifier rules for welded aluminum alloy 5083. Therefore, the values should be lower in the structure.

For the procedure, it becomes indispensable to use appropriate geometric shapes in the structural members that allow a homogeneous distribution of the stresses and reduce the points of concentration of stresses (Hard Points) in the development of the results. In this way, it was possible to for the stresses with the highest values to be found in the structures of the Naca profiles of the boat on the pontoons of the hull and the wet deck. This is in accordance with the distribution function of stresses in the hull by the action of the slamming load. In the case of the maximum deformation, it was shown in the wet deck in the sector of the bow with a value of 4.99 mm (Fig.14), and in the case of the maximum stress, it had a value of 108.37 MPa (Fig. 13) in the area of the structure in the Naca profiles that join the pontoon with the upper hull.

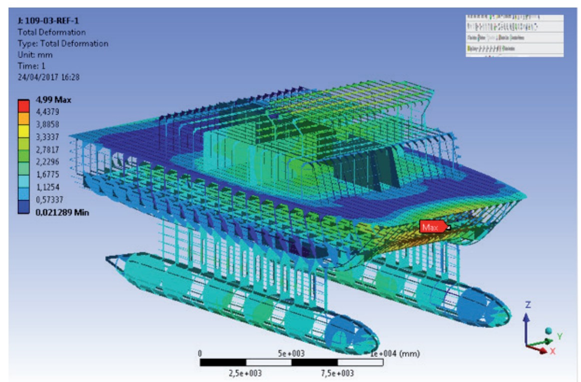
Fig. 13. Maximum Vessel Stress 108.37 MPa.



Source: Authors.

According to the classification rules for HSC type boats Part 3 Structures, Equipment, Chapter 3 Hull Design - Aluminum 2018, they cannot exceed the following permissible stresses and can be analyzed in three elements (Equations 3, 4 and 5) Sheets, Reinforcements and Primary Members, for which the validation of the results obtained in the area where the greatest stresses of the structure will be presented was made (Figs. 15, 16 and 17).

Fig. 14. Maximum Vessel Deformation 4.99 mm.

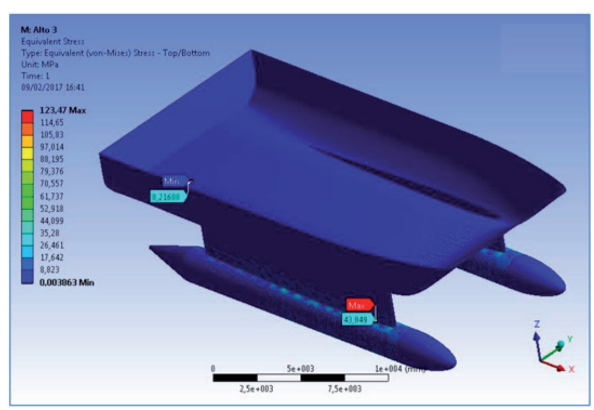


Source: Authors.

Stresses in sheets

Hull of the boat

Fig. 15. Vessel Hull.



Source: Authors.

Maximum stress: 43.09 MPa

$$\sigma_e = 240 f_1 \; N / nm^2 \tag{3}$$

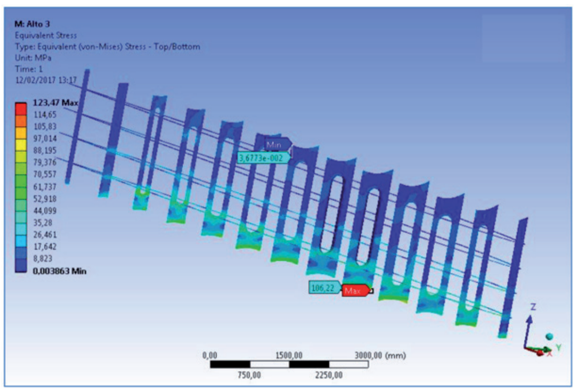
$$\sigma_e = 240 * (0,9) \; N / nm^2$$

$$\sigma_e = 216 \; N / nm^2$$

Reinforcement stresses

Transverse reinforcement Naca profile structure

Fig. 16. Transverse Stress Pontoon Profile Structure.



Source: Authors.

Maximum stress: 106.22 MPa

$$\sigma_e = 221 f_1 \; N / nm^2 \tag{4}$$

$$\sigma_e = 220 * (0,9) \; N / nm^2$$

$$\sigma_e = 198 \; N / nm^2$$

Primary member stresses

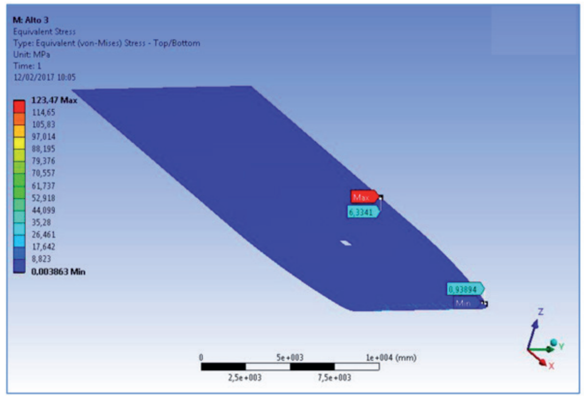
Main Deck

$$\sigma_e = 180 f_1 \; N / nm^2 \tag{5}$$

$$\sigma_e = 180 * (0,9) \; N / nm^2$$

$$\sigma_e = 162 \; N / nm^2$$

Fig. 17. Main Cover.



Source: Authors.

From what was previously observed, it could be seen that the stresses on the structures was kept well below the maximum allowable stress presented by the Slamming event adequately under the parameters of the DNV GL classification society in a Conceptual Design stage.

Conclusions

The design and the results obtained, for the case study, comply with the criteria established by GL. This, as a result of the application of the loads to which the boat is submitted in its hull and the junction deck during the Slamming event, results in a structure that presents a maximum stress of 108.37 MPa and a maximum deformation of 4.99 mm, being 13.3% below the value characterized by GL. In future work, and to ensure the structural integrity of the ship, the events of Splitting Moment, Tortional Moment and/or any combination of the above should be analyzed.

The process developed in this study, obtained adequate results to the parameters established by the Classification society by means of the use of FEM and the integration of different computer tools, making it a reference for the application of this in any type of vessel for further study in the Slamming event, because it has allowed to evaluate the designed structure by means of the obtaining of the stresses and deformations, characterizing those structural members under superior stresses by the loads of the system and their structural response. The use of computational tools for modeling, allows to analyze, from initial stages, to the designs of any type of vessel, obtaining, in perspective, the possible failures of an engineering project, allowing for correction prior to construction of any structural optimization with the purpose of obtaining a functional design to satisfy the needs of the shipowner and the reduction of costs in a shipyard.

References

[1] H. EVANS, "Basic Design Concepts," A.S.N.E. Journal, pp. 671-678, 1959.

[2] H. MURCIA, Application of the Finite Element Method in the Structural Analysis of a Swath-type Patrol Boat, Cartagena de Indias: Escuela Naval de Cadetes "Almirante Padilla", 2017.

[3] GERMANISCHER LLOYD, Analysis Techniques, Hamburg: GL, 2013.

[4] P. Y. ARIANTO, A. ZUBAYDI, B. PISCESA Y TUSWAN., "Experimental and Numerical Bending Analysis of Steel/Resin-Talk Sandwich Material," IPTEK , pp. 123-128, 2019.

[5] E. ALTUNSARAY, D. ÜNSALAN, G. NEŞER, K. T. GÜRSEL Y M. TANEr, "A parametric study for static deflections of symmetrically laminated rectangular thin plates," Scientific Bulletin "Mircea cel Batran" Naval Academy, 2019.

[6] D. FUENTES , M. SALAS, G. TAMPIER Y C. TRONCOSO, Analysis and Design of Marine Structures - Guedes Soares & Shenoi, Londres , 2015.

[7] W. WU, B. LIU Y C. GUEDES, "Ultimate strength analysis of a SWATH ship subjected to transverse loads," Marine Structures, vol. 57, pp. 105-120, 2018.

[8] DIMAR, "Climatology of the Main Ports of the Colombian Caribbean: San Andres and Providencia," Dirección General Marítima Colombia, Cartagena, 2010.

[9] DNV GL, Rules for Classification High Speed and Light Craft, Part 1 General Regulations Chapter 2 Class Notations, Høvik: DNV GL , 2018.

[10] GERMANISHER LLOYD, "Classification and Construction Rules for High Speed Craft," GL, Hamburg, 2012.

[11] B. PHELPS, Determination of wave loads for Ship Structural Analysis, Melbourne: Australian Departament of Defence, 1997.

[12] C. FELIPPA, Introduction to the Finite Element Method, Boulder: University of Colorado at Boulder., 2004.

[13] ANSYS, "Manual," ANSYS, 2012.

[14] T. KURKI, "Utilization of integrated design and mesh generation in ship design process," Rakenteiden Mekaniikka (Journal of Structural Mechanics) , pp. 129-139, 2010.

[15] M. COSTACHE Y G. JAGITE, "Global Strenght Analysis in Head Waves, for an Offshore Support Vessel," Asian Journal of Applied Science and Engineering, pp. 73-88, 26 septiembre 2014.

[16] L. LIAO, A Study of Inertia Relief Analysis, Denver, Colorado: ASME, 2011.

[17] DNV GL, Finite Element Analysis, Hamburg: DNV GL, 2015.

[18] A. MOLAND, Maritime Engineering Reference Book, Burlington: Elsevier, 2008, p. 46.

[19] J. BJORHUS, "Jonathan Turner, Airplane Engineer," The Seattle Times, 18 Octubre 1995.

[20] R. W. CLOUGH, "Original Formulation of the Finite Element Method," Finite Elements in Analysis and Design, pp. 89-101, 1990.

[21] J. H. ARGYRIS, Energy Theorems and Structural Analysis, New York: London Butterworths, 1955.

[22] M. M. Y.V. SATISH KUMAR, "Finite element analysis of ship structures using a new stiffened plate element," Ocean Research, vol. 22, pp. 361-374, 2000.

[23] P. PIALA Y T. KALINA, "Finite Element Method in Ship's Industry," Electronical Technical Journal od Technology, Engineering and Logistic in Transport, pp. 182-186, Diciembre 2010.

[24] D. SERVIS, G. VOUDOURIS, M. SAMUELIDES Y A. PAPANIKOLAOU, "Finite element modelling and strength analysis of hold No. 1 of bulk carriers," National Technical University Athens Magazine, 2004.

[25] A. B. TRICLAVILCA TENORIO, D. A. MESTANZA RODRIGUEZ AND F. F. RIVERA TIRADO, "Simulation of Numerical Systems through Finite Elements of a River Vessel," International Conference IDS 2013, July 17, 2013.

[26] J. F. USECHE, El Método de los Elementos Finitos en Mecánica de Sólidos: Conceptos y Formulación Basica, Cartagena: Universidad Tecnologica de Bolivar, 2006.

[27] S. KOS, D. BRČIĆ Y V. FRANČIĆ, "Comparative Analysis of Conventional And Swath Passenger Catamaran," Journal of Maritime Studies, 2009.

[28] M. SALAS, "Analysis of Mechanical Structures with the Finite Element Method," Author, Valdivia, 2014.

[29] D. SOURCES, Analysis and Structural Optimization of a multihull designed in Aluminum, Valdivia: Universidad Austral de Chile, 2014.

[30] J. T. CELIGÜETA LIZARZA, Método de los Elementos Finitos para el Análisis Estructural, San Sebastian: University of Navarra, 2011.

[31] J. E. HURTADO, Introduction to Structural Analysis by Finite Elements, Manizales: Universidad Nacional de Colombia, 2010.

[32] R. COURANT, "Variational Methods For the Solution of Problems of Equilibrium and Vibrations," Bulletin of the American Mathematical Society, 1949.

Jib crane bearing selection through simulation

Selección de Rodamientos mediante Simulación para Brazo de Carga

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Abstract

Through the corrective maintenance process of a bearing, regardless of its origin, certain anomalies related to its main elements, due to the condition of the type of maintenance, are expected. This was the case of the jib crane of the Caribbean Submarine fleet, used mainly to load the wiring and charging sockets for the supply of electrical energy to the Submarines. During a routine operation, it malfunctioned and stopped working without warning. An inspection was carried out in which corrective maintenance was deemed necessary, it was at the time that the bearing support was uncovered and its advanced state of deterioration was observed. Being this the main failure, and through application of engineering principles and simulation software, the reason for the deterioration was determined, and the optimal bearings for the correct operation of the jib crane were selected.

Key words: Jib crane; Structure; Bearing, Simulation

Resumen

Durante el proceso de mantenimiento correctivo de un rodamiento, independiente de su origen, se espera encontrar ciertas anomalías relacionadas con sus elementos principales, esto debido a la condición del tipo de mantenimiento. Este fue el caso del brazo de carga de la Flotilla de Submarinos del Caribe, utilizado principalmente para cargar el cableado y la toma de carga en el suministro de energía eléctrica a los Submarinos. Durante una operación rutinaria presentó fallas y dejó de funcionar sin dar previo aviso. Se llevó a cabo una inspección en la que se determinó que era necesario realizar un mantenimiento correctivo, fue en el momento en que se destapó el soporte de los rodamientos que se evidencio el avanzado estado de deterioro de estos, siendo esta la falla principal y mediante aplicación de los principios de ingeniería y software de simulación, se logró determinar la razón del deterioro y seleccionar los rodamientos óptimos para el correcto funcionamiento del brazo de carga.

Palabras claves: Brazo de carga; Estructura; Rodamiento, Simulación.

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Introduction

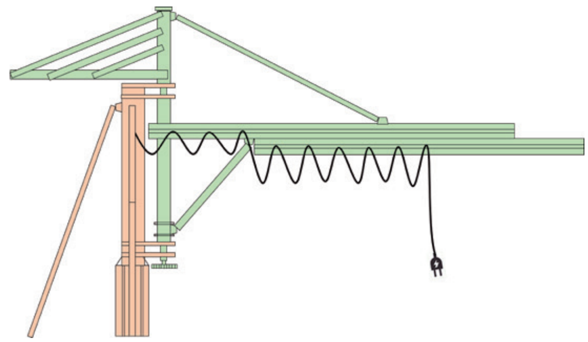
The jib crane was built in the year 2017, it is defined as a structural element designed to load the wiring and the charging socket of the submarines; it is operated by a control panel, with 8 buttons that control 4 motors. This, with the main purpose of charging the batteries of the submarine with the required external current. This system must comply with 4 degrees of freedom that allow the operator to precisely transport the required components.

This mechanical structure seen in Fig. 1 is divided into two parts, the fixed part (red color) and the mobile part (green color). The latter, consists of 7 elements: the load socket, wiring, rotation axis, a tray with the counterweights, a main beam, an upper support and a lower support, with a total 3997 kg weight, which in turn rotates on a bushing located in the upper support and two bearings located in the lower support, which will be explained later. Fig. 1 shows the axis of rotation as the element that connects the seven elements mentioned above, with the anchoring of the spring through a mast and six diagonal supports, called the fixed part.

The movement of the jib crane is provided by four motors located along its moving part. The main one is parallel to the mast and works by means of a chain that allows for orientation movement, in the horizontal plane, with a restriction of 180º at no more than 5 rpm; the other motors are located on the main beam and provide for the movement of translation of the beam, translation of the hoist motor through the beam and lifting of the load socket. In its fullness they allow it to move according to operation specifications.

Recently, the jib crane began to malfunction in its orientation movement, apparently due to the low efficiency of the main motor, forcing the operator to provide manual support to complete the objective. After inspection, disassembly, and verification of electrical elements such as motors, wiring and control panel, it was determined that was a mechanical failure that would most likely be in the shaft. After disassembly, during the bearings inspection, it was found that, due to

Fig. 1. Structure of the jib crane.



Source: Authors.

their deteriorated condition, the suitability of these elements for this application needed to be recalculated in order to comply with the design parameters or a solution that would provide greater reliability to the design had to be found.

At the top of the bearing housing there was a tapered roller bearing and at the bottom of the housing there was a single row ball bearing with angular contact, as shown in Fig.2 and Fig.3 respectively. According to the technical specifications both elements meet the design criteria. However, commercially there are other options that allow for optimizing the equipment, while minimizing wear and extending its useful life, such as a single row ball bearing with angular contact or a deep groove ball bearing.

Likewise, the evidence of wear at the ends of the metal part as shown in Fig. 4, indicated the need for machining the bearing housing to eliminate the existing wear, in addition to a proposal for bearing selection through simulation based on loads and calculations of support reactions to determine the forces applied.

Theoretical Framework

Bearings are objects designed to keep their moving parts in the proper position, decrease friction and facilitate movement. They can support axial loads or loads in the direction of the axis, tangential or perpendicular loads to the direction of the axis and combined loads. [4]

Fig. 2. Upper bearing of the jib crane bracket.

Source: Authors.

Fig. 3. Lower bearing of the jib crane bracket.

Source: Authors.

Fig. 4. Wear found at the base of the lower bearing.

Source: Authors.

They generally consist of two rings or discs with raceways, rolling elements and a structure that keeps the rolling elements and the guides separate, called a cage. [2]

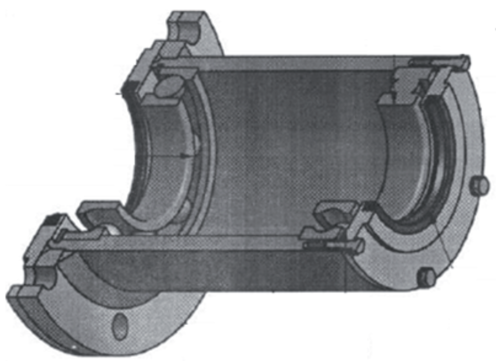
According to the SKF bearing selection manual, there are different types of bearings with characteristics that make them suitable for some applications more than others. Cylindrical roller bearings can support higher radial loads compared to a deep groove ball bearing, spherical ball bearings can allow a greater degree of freedom to the shaft, etc. Other types of bearings include spherical roller bearings, single direction thrust ball bearings, needle roller bearings, which are widely used in small spaces, and tapered roller bearings, among others. [2]

The arrangement of the bearings is very important in its properties, they can be oriented face to face or in "X" configuration, back to back or "O" configuration, and finally, in tandem. Again, each configuration increases or decreases the properties of the bearing as required. In the specific case of the jib crane, as can be seen in Fig. 5., the lower support consists of two bearings separated at a distance of 200 mm and crossed by a 100 mm diameter shaft in a 180 mm support.

Methodology

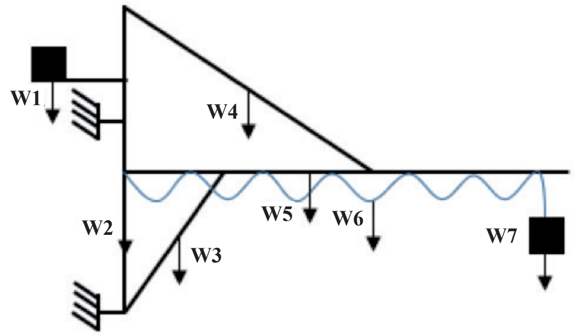
Starting the calculation phase to determine the arm loads on the bearings, it was necessary to separate

Fig. 5. Isometric section view of the lower jib crane support.



Source: Authors.

Fig. 6. Structural components of the jib crane.



Source: Authors.

the components as shown in Fig. 6, estimating the weights of some of the objects, considering that the design drawings did not include this data, and others simply do not have any drawings. For this we used the expression (1) or density formula. The counterweights were the easiest, since their volume was the only variable requiring identification (that of a rectangular prism) and the density formula of the object was used to clear its weight. In the case of more complex objects, such as the tray where the counterweights are supported, the task was more interesting, since it was necessary to divide the structure in geometric figures of known volume and add them together to use the same formula mentioned above. Other elements had the weights in the design drawings.

For the steel parts a density (ρ) of 7850 kg/m^3 was used, and for the counterweights specifically 2400 kg/m^3. [1]

$$\rho = \frac{m\ (kg)}{V\ (m^3)} \tag{1}$$

In this way the approximate weight of the structure was obtained (see Table 1) and from this data, the exercise was worked as a structure supported by two supports on which there will be some reactions or forces contrary to the forces exerted by the weights.

In order to get the reactions of the components of the jib crane, it was imperative to calculate the distances, so by means of the equations of moments (2) and forces (3), the desired result was achieved. [1].

$$\Sigma M_x = 0 \tag{2}$$

$$\Sigma F_x = 0 \tag{3}$$

Due to the working conditions of the jib crane, emphasis was placed on the most critical case, consisting of the fully extended arm and the charging socket at the opposite end of the axis, simulating the position of the jib crane during powering of an underwater unit. Based on the traditional free body diagram, where the reactions in the supports are found, and with the help of the tool "Bearing select" of the company SKF [3], together with the existing design parameters and dimensional restrictions, a simulation was recreated to provide the optimal type of bearing to be installed in the lower support of the jib crane.

Table 1. Weight of the components.

Name	Weight (KG)	Force (N)
W1	1100	10780
W2	685	6713
W3	126	1234
W4	188	1842
W5	1308	12818
W6	480	4704
W7	110	1078
Total	3997	39169

To begin the simulation, the concrete cases that complied with the established design dimensions (internal and external diameters and width of the bearing) and available in the SKF simulator were established, and directed towards five alternatives.

1. Bearings installed.
2. Rigid ball bearing*.
3. Angular contact ball bearing in face-to-face and back-to-back arrangement
4. Taper roller bearings in face-to-face and back-to-back arrangement.

* Due to the condition of being a rigid ball bearing, the simulation in face to face or back to back position are equivalent.

The following parameters were considered to determine the optimal solution

1. Static safety factor above 1.5. (S_0).
2. Basic dynamic and static load capacity (*C*C y C_0).
3. Lubrication interval.
4. Minimum load for operation.

Below is a description of the different parameters to be considered. The static safety coefficient, for example, allows the designer to have certain tolerance in case the operator or owner decides to vary the loads of the component without running the risk of damaging the bearings by such movements. The basic dynamic load rating is the load whose magnitude and direction are constant and under which the bearing reaches the nominal life of one million turns [2]. The lubrication interval is very important since the bearings are sealed and the structure must be dismantled to perform this operation. The minimum load is an operating restriction that indicates if the existing weight is in accordance with the bearing or is below it to exert the necessary pressure for operation. A bearing that exceeds the requirements is not desirable, since it would be assumed that the structure is over-dimensioned, affecting its functionality and efficiency.

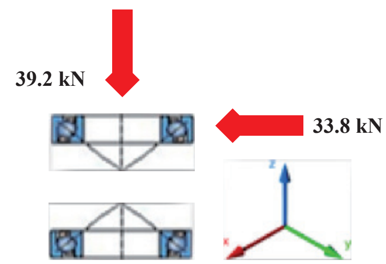
The bearings selected for the simulations were:

1. Single row tapered roller bearing 30220.
2. Rigid ball bearing 6220-2RSR.
3. Single row angular contact ball bearing 7220 BECBP.

Results and Analysis

The axial and radial reactions were determined by the sum of moments and forces, resulting in 39.2 kN and 33.8 kN respectively (see Fig 7). This data was required by the tool "Bearing select" of the company SKF to start the simulation work.

Fig. 7. Location of reactions in the bearings.



Source: Authors.

Case 1: Bearings installed

The simulation was not possible since the simulator does not allow such a configuration between different bearing classes, and this specific case includes a tapered roller bearing together with a single-row ball bearing with angular contact.

Case 2: Rigid ball bearing

Table 2. Result of the simulation case 2.

Parameter	Simulation
S_0	Infinity
C	127kN
C_0	93kN
Lubrication	Does not register
Minimum load	Does not comply

The parameters described in Table 2 show that the static safety factor tends to be infinite, it does not register any lubrication interval and does not meet the minimum load established in the design.

Case 3: Angular contact ball bearing in a face-to-face arrangement.

Table 3. Result of the simulation case 3.

Parameter	Simulation	
S_0	2.31	3.76
C	143kN	
C_0	134kN	
Lubrication	Does not register	
Minimum load	51.1kN	21.4kN

The parameters described in Table 3 show that the static safety factor varies according to the location of the bearing, with the S_0 of the upper bearing 2.31 and the lower bearing 3.76, as well as, a minimum load of 51.1 kN and 21.4 kN respectively. No lubrication interval is recorded.

Case 4: Angular contact ball bearing in back-to-back configuration.

Table 4. Result of the simulation case 4.

Parameter	Simulation	
S_0	4.87	21.4
C	143kN	
C_0	134kN	
Lubrication	23800h	
Minimum load	24.2kN	5.52kN

It records values for all variables, so it is shown as an eligible alternative.

Case 5: Taper roller bearings in a face-to-face configuration.

Table 5. Result of the simulation case 5.

Parameter	Simulation	
S_0	8.59	7.32
C	304kN	
C_0	320kN	
Lubrication	170000 h	
Minimum load	5.17kN	5.17kN

Case 6: Tapered roller bearings in back-to-back configuration.

Table 6. Result of the simulation case 6.

Parameter	Simulation	
S_0	6.7	131
C	143kN	
C_0	134kN	
Lubrication	Does not register	
Minimum load	Does not comply	

The parameters described in Table 6 show that it does not register a lubrication interval and does not comply with the minimum load established in the design.

Cases 4 and 5 were the only ones that met the requirements outlined above. Analyzing these bearings more closely, it should be noted that the static safety factor of the upper bearing is lower for case 4 and the opposite case for case 5, similar to the tapered roller bearings, where the loads are distributed equally between the two bearings, while in the angular contact ball bearing, the loads are mostly assumed by the upper bearing. This data can be directly related to the minimum load required in each location, as seen in case 5, where they are equal, as opposed to case 4, where the load for the upper bearing is almost five times the load of the lower one.

It was expected that due to the high basic dynamic and static load capacities of the tapered roller bearing, its lubrication time would be so long. However, according to the SKF bearing manual it is unreliable to have a lubrication time longer than 30,000 hours [2].

Finally, since price is one of the fundamental parameters for the decision to change the bearings of the jib crane, it is not a relevant factor in this case, since the cost of the project in general, is significantly higher than the cost of the bearings. However, if a bad decision is made, it can lead to reprocessing, which increases project costs and decreases equipment availability.

Conclusions

Considering the results of the simulations of the cases studied, the recommendations of the SKF company and the calculations made, it was concluded that the bearings to be selected are those of angular contact ball 7220 BECBP in a back-to-back arrangement, as indeed it was done and installed. The current state of the support with the bearings installed can be seen in Fig.8.

Fig. 8. Lower jib crane support after maintenance.

Source: Authors.

It was very helpful to have the support of the Engineers and Technicians of the Corporación de Ciencia y Tecnología para el desarrollo de la Industria Naval, Marítima y Fluvial (COTECMAR) who showed their expertise to take on the challenge of performing the first maintenance of the jib crane in the main dock of the Caribbean Submarine Fleet and finish the project successfully.

Bibliography

[1] BEER, F., JOHNSTON, E. AND CORNWELL "Vector Mechanics for Engineers,"2010.

[2] SKF “Rodamientos” October 2015 [Online]. Available: https://www.skf.com/co [Accessed 4 August 2020].

[3] SKF “Bearing select” October 2015 [Online]. Available: https://www.skf.com/co/support/engineering-tools/skf- plain-bearing-calculator [Accessed 4 August 2020].

[4] SENA “Mantenimiento de rodamientos y cojinetes” March 1995 [Online]. Available: https://repositorio.sena.edu.co/bitstream/11404/765/1/mantenimiento_rodamientos_cojinetes.pdf [Accessed 4 August 2020].

A Preliminary Study of Routing Protocols in a Tactical Data Link Ad Hoc Network in Colombian Maritime Scenario

Estudio Preliminar de Protocolos de Enrutamiento en una Red Ad-Hoc de Enlace de Datos Tácticos en un Escenario Marítimo Colombiano

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Abstract

Tactical Data Link (TDL) systems are a kind of Mobile Ad Hoc NETwork (MANET) used in diverse maritime operational environments such as natural disasters, surveillance, maritime search, and rescue. A TDL network is usually composed of nodes or units representing surface ships, submarines, and aircrafts able to participate in maritime operations. A routing protocol is required to establish communication between nodes, which guarantees the route from the source node to the destination node. A TDL has been developed in the Colombian Caribbean Sea (CTDL). However, no efficient routing protocol has been implemented. This works to perform a preliminary study to implement an appropriate routing protocol for the CTDL.
Local environment constraints, in addition to the chosen protocols' performance analysis, will provide preliminary alternatives for a routing protocol with acceptable efficiency. This article provides a background of ad-hoc networks routing protocols, a description of the Colombian Caribbean maritime operational environment, a comparative analysis of routing protocols, and a discussion of conclusions and future developments regarding CTDL.

Key words: Routing, MANET, Table Driven, tactical data link.

Resumen

El sistema de enlaces tácticos de datos (Tactical Data Link, TDL) es una especie de red móvil Ad-hoc (Mobile Ad-Hoc Network, MANET) utilizada en diversos entornos operativos marítimos como desastres naturales, vigilancia, búsqueda y rescate en el mar, entre otros. Por lo general, una red TDL se compone de nodos o unidades que representan buques de superficie, submarinos y aeronaves capaces de participar en operaciones marítimas. Los protocolos de enrutamiento son necesarios para establecer la comunicación entre los nodos que garantiza el establecimiento de la ruta desde el nodo de origen al nodo de destino. Se ha desarrollado un TDL en el mar Caribe Colombiano (CTDL); sin embargo, no se ha implementado ningún protocolo de enrutamiento eficiente. Por lo tanto, el objetivo de este trabajo es realizar un estudio preliminar para implementar un protocolo de ruteo apropiado al CTDL.
Las restricciones de entorno local, además del análisis de rendimiento de los protocolos elegidos, proporcionarán candidatos preliminares para un protocolo de enrutamiento con una eficiencia aceptable. El artículo proporciona antecedentes de protocolos de enrutamiento en redes Ad-Hoc, una descripción del entorno operativo marítimo del caribe Colombiano, un análisis comparativo de los protocolos de enrutamiento y unas conclusiones y desarrollos futuros con respecto a CTDL.

Palabras claves: Protocolos de Enrutamiento, MANET, Enlace de datos tácticos.

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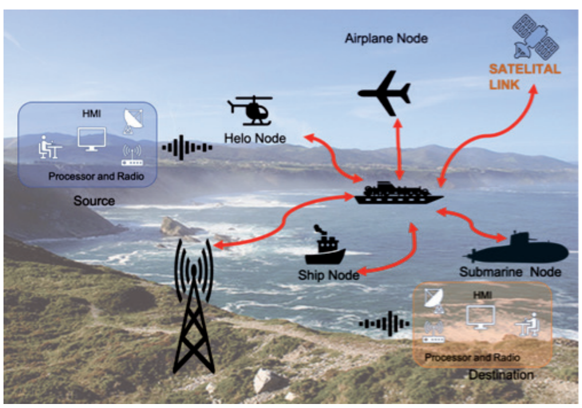
Introduction

A TDL is an ad-hoc [1] network with a specific task, characterized for having two or more units (nodes) equipped with wireless communications with network integration ability establishing a direct or indirect (through relay nodes) contact. TDL features are self-organized and adaptative. Even when data is underway, the path from the source to the destination node requires no administration system. Ad-hoc networks could have different forms, such as mobile, standalone, or network of any other system.

Fig. 1 describes the functional elements of a TDL, which include a source node/unit willing to establish communication with another node called destination, directly or through relay nodes. Note that nodes have a Human Machine Interface (HMI), a processor module, and a transmission module that allows for information broadcasting.

Fig. 1. Tactical Data Link.



Most TDLs are developed either by the North Atlantic Treaty Organization (NATO) or by private commercial companies. These developments are not open source, generic, or for general use. The customizing network is not available to the end-user, and the original equipment manufacturer is not allowed to release the network or system security parameters.

For the Caribbean Sea scenario, the mentioned TDLs do not fit all information requirements such as weather conditions, units positions, sea state, or the performance of the participating teams, among others.

Although there has only been one TDL implementation in Colombia [2], no evidence of routing protocols has been found in its systems. Therefore, introducing routing protocols is necessary to contribute to the efficient development of the Colombian Tactical Data Link (CTDL).

In the early 1970s, the first ad-hoc networks, packet radio systems, were implemented [3]. They used routing protocols for mobile networks and faced restrictions such as:

1. High power consumption
2. Bandwidth restrictions
3. High Bit Error Rate (BER)

Currently, routing protocols have successfully overcome those constraints and have reached maturity to fulfill end user's needs.

This article provides an overview to recommend the appropriate TDL routing protocols to work in a specific maritime environment. To achieve these objectives, this paper provides a background on ad-hoc networks, followed by a description of the maritime operational environment in the Colombian Caribbean Sea and a discussion regarding routing protocols, including a comparative analysis among them and, finally, states the conclusions and expectations for future developments of the CTDL.

Background

Ad-hoc networks [4], [5] are wireless means to set up communications in different kinds of unexpected maritime environments, jungles, and deserts, where no established communications systems are available. Each node should detect other nodes or units present in the operational scenario to perform a handshake to guarantee an active link, communication, data, and network services, among them. Concerning these issues, ad-hoc networks do not solely need to detect other nodes, but they must also identify the types of neighboring node devices and their features. The intrinsic characteristics of the ad-hoc-network include its infrastructure-less configuration without a predetermined topology or centralized control. There is no fixed base radio station, router, wires, or fixed routes, whereby routed information will change as per network node mobility changes, which will be reflected in the link connectivity. Ad-hoc networks face many other constraints, such as different hardware brands (computers, mobile phones, communication equipment, etc.), and power consumption becomes critical due to the relay of information packets between nodes, which requires hardware to work permanently.

Some of the challenges and difficulties [1] that ad-hoc mobile networks face are:

1. The use of the radio spectrum is regulated by the government of each country. While performing tests, the ISM (Industrial, Scientific, and Medical) band, whose frequencies are clustered around 2.4 GHz, could be used. Nevertheless, end-users must verify the availability of the spectrum for each specific case.
2. Media Access is a significant challenge [1]. Unlike wire networks, Ad-hoc network control is not centralized, and there is no synchronization time. Therefore, *Time Division Media Access (TDMA)* or *Frequency Division Media Access (FDMA)* schemes are not feasible, and most of the *Media Access Control (MAC)* protocols do not manage mobile nodes; hence the *Quality of Service (QoS)* is weak. Media access must be distributed fashion mobile nodes allow MAC protocols to maintain access in the same channel, whereas at the same time, avoiding collisions with neighboring nodes.
3. *Transmission Control Protocol (TCP)* performance [1] is vital, considering that it provides network flow and congestion control. TCP is a connection-oriented protocol; thus, a connection is required before the data transmission. TCP calculates RTT (Round-trip time) and the packet loss rate between the source and the destination nodes. TCP assumes all network nodes are static; therefore, it is not able to detect if the node relay mobility affects RTT or packet loss, which, in turn, becomes another Ad-hoc network challenge.
4. In terms of security ad-hoc networks are intranets [1]. Such communications are already isolated but not warded from attackers. Neighbor authentication is used to classify friend or hostile relay nodes, requiring encrypted and protected communications due to multiple node involvement. Packet origin and ID flow or label authentication are mandatory.
5. Last but not least, routing [1]. When used, mobile nodes link and break in an indeterministic way. Bellman-Ford route algorithm was used in early ad-hoc networks to perform and update routing information due to the random movement of the nodes and the network's topology continuous changes. Conventional wireless routing protocol performance proved to be insufficient for Ad-hoc networks, hence the need to improve protocols and adapt them to new topologies. State of the art provides various routing algorithms.

For this study, the important constrain is item #5. As mentioned in the introduction, the CTDL lacks a routing protocol. Hence, the initial requirement is to know the operational environmental conditions where the CTDL will perform to determine the routing protocol. This will allow the designer to determine the CTDL features such as network size, node quantity, node mobility features, as well as environmental conditions such as oceanic status, wind, etc.

Maritime Operational Environment

The CTDL project [6] describes the Colombian Caribbean Sea environmental characteristics addressing end-user needs. Its scope is to enhance the operational direction performance, sensor integration, and information exchange in case of natural disasters, maritime domain awareness, and contributing to decision-making processes.

Usually, maritime operations are carried out in groups of units (nodes for ad-hoc networks), which can be surface vessels, aircraft, or submarines, according to each specific situation. Transmission of tactical information among them is fundamental to have a real-time scenario that enables operations coordination. The system must be secure and end user friendly, regarding the appropriate bandwidth use, and all the required software and hardware tools to visualize standard operation picture and information exchange among participant units.

The CTDL scenario composition is four vessels, one submarine, and two aircraft (one helicopter and one airplane). The analysis is performed considering each unit as a node having specific behaviors such as speed and altitude sensors and variables affecting the network like the line of sight and distance between nodes.

Weather conditions can influence a TDL design and its routing protocol. Therefore, factors such as humidity, air salinity, high temperatures, rainy and dry seasons, and all typical tropical conditions must be considered.

Now, certain features need to be considered for routing protocols to be able to perform in the maritime environment CTDL.

A. End-User Needs.

Need detaches from the essential CTDL requirement:

- Allowance of any node to join the network automatically and freely at any time.
- Automatic network management.
- Automatic packet relay to guarantee communications between source, intermediate, and destination nodes.
- The node array capacity must share messages automatically to accomplish the assigned mission.
- Implemented routing protocols should be aware of processes involving node capability, mobility, and bandwidth consumption.

B Functions and management.

- Tactical information, including all exchangeable situation awareness messages to obtain a common scenario among participant nodes, upgrade information, configuration reports, change reports, position and contact reports, daily reports, and all kinds of correlation information.
- The network must contemplate media access criteria and requirements, QoS, to control and organize the Ad-hoc network, specifically the management of routing protocols.
- Standard messaging system to control and share information to and from the actuators and sensors.

C. System.

- It should operate in the range of HF, VHF, and UHF bands.
- Allow any node to join the network automatically at any time.
- Change network topology upon request.
- CTDL should maintain source-destination links even if the relay node fails.
- Automatic network management.

D. Integration capacity.

- To Surface vessels. Nowadays, the system is incorporated into the command and control system, and it requires integration with other ships, helicopters, or submarines in the operations area.
- To Submarines, when a submarine navigates at the surface, CTDL requires sharing actuators or sensors information with other units or nodes' and must allow command and control message exchange.
- To Helicopters, its role is essential in search and rescue, during tsunami disasters, etc. Like other units, helicopters are required to share tactical information with other nodes.
- To airplanes, Colombian Maritime Patrol Aircrafts (MPA) have no CTDL Capability yet, which is mandatory for search and rescue (SAR), shipwreck search and assistance, and

disaster assistance, among other operations. Likewise, airplanes require TDL capability to share tactical information of processes involving the Safety of Life at Sea.

These features determine the implementation design of the routing protocol. End-user-needs can show the network topology. Functions and management can rule the network's size and density. The system offers the electromagnetic spectrum and bandwidth usage. Finally, integration capability drives network node quantity.

A designed scenario is essential; the CTDL simulation model is composed of two surface vessel nodes, one submarine node, one helicopter node, and one airplane node, as described in Table 1. The design purpose is to establish a future simulated scenario capability. This model must have assumptions, *i.e.*, all nodes must be in the line of sight range, and nodes should establish communications in the same frequency even if there are different hardware brands.

From Table 1, and the CTDL features, it is possible to infer that:

1. Regarding network node mobility (items 1 and 8 in table 3), according to CTDL's configuration, it is considered a moderate and low-density network.

2. Regarding delays and latency (item 4 in table 3), they are mobile and have low speed compared to ground vehicles or aircraft [7] [8] [9], making latency, messaging delays, and route restoration manageable and tolerable. However, as nodes speed increases, these variables become critical due to faster changes in distances among distribution nodes.

3. Regarding Bandwidth usage (item 5 in Table 3), nodes have brand diversity of communications equipment, technologies, capabilities, and performances that would limit available bandwidth and communication channel use and consumption. These limitations impose additional tasks to control messages required for routing protocols operation.

4. Regarding the routing metric (item 6 in Table 3); As already mentioned, the CTDL network is not expected to be highly congested; therefore, the route selection criteria lead to choosing the shortest route, which is more reliable than the least busy.

5. Regarding size and node quantity (item 7 in Table 3), CTDL is a small network compared to standard TDL systems generated by NATO, where the networks can have from two to a range between 100 and 200 nodes or users (e.g., Link-22 [10], corresponding to the state of the art of naval TDLs, which can handle up to 130 stations). CTDL has 25 nodes, expandable up to 100 in the network. Due to network size and the light messaging load per-node, information traffic is not expected to be as high, facilitating broadband use.

6. Regarding Multicast capability (item 9 in Table 3), the directed transmission is not allowed due to the use of omnidirectional antennas. However, the system can broadcast, multicast, or unicast any communication as required. Nevertheless, the casting method is an optimization issue in

Table 1. CTDL Scenario Composition.

Node #	Type of Unit	Speed	Speed rate	Height	Bandwidth	LOS	LOS rate
0	Vessel 1	15 N	1	0 ms	Vhf/Uhf	20 Miles	1
1	Vessel 2	15 N	1	0 ms	Vhf/Uhf	20 Miles	1
2	Submarine	5 N	0,33	-2 ms	Vhf/Uhf	10 Miles	0,5
3	Helicopter	100 N	5	500 ms	Vhf/Uhf	60 Miles	3
4	Airplane	130 N	6,2	1500 ms	Vhf/Uhf	60 Miles	3

the sense that the load on messages changes with the type of broadcast.

7. Regarding power (item 13 in Table 3), consumption management is not required as part of the study since participating nodes or units have constant and unrestricted power source availability.

8. Regarding node relay capability (item 14 in Table 3), Ad-Hoc and TDL network nodes must be able to serve simultaneously as source and relay. CTDL design has this capability.

9. Regarding the use of route cache/table expiration timers (item 15 in Table 3), CTDL uses GPS information in its messaging to determine node position among the established network, as well as a synchrony tool when using TDMA as a media access technique; that is, the use of GPS could leverage in algorithms that require synchrony in expiration timers.

Routing Protocols

There are different routing protocol classifications, though Setup is the best known one. Kuosmanen [11] proposes other rankings based on various technical characteristics:

- Communications model. It depends on the channel usage: single or multiple.
- Structure, the nodes are uniform when all nodes receive and transmit in the same way, this structure is flat, and there is no pecking order. Otherwise, if the nodes are not uniform, there is a hierarchy structure, and each node routing is given by its neighborhood status.
- Information status. It is based on the way information is obtained and how nodes interact with each other. These protocols are called topological. Another classification criterion by destination; nodes store only topological information of its neighborhood nodes.
- Setup. This classification is the best known. It is called 'proactive' when information is continuously sent (Table-Driven) and reactive when information is irregularly sent (On-Demand).
- Transmission mode may be unicast or multicast.

Regardless of how protocols are classified, the classification depends on their specific use, and they can be classified independently of the model. This article is based on the Setup model and breakdowns, as shown in Fig. 2 [1] of "Table-Driven" and "On-Demand" systems.

Fig. 2. Routing Protocols.

Setup models are described as follows:

A. Proactive or Table-Driven Protocols.

Coya Rey [12] explains MANET as the use of packets to discover nodes in a network and the path to reach them from or to a specific node. A given supposition is that all routes are already defined and, at some point in time, used. So, a table works to maintain updated route information; the main merit is that route information is permanently available, providing an easy way to establish the path from/to nodes. One of the drawbacks in MANETS is the existence of high amounts of data at each node, causing the network to slow down and the update process to be sluggish, especially when links are broken.

Venkat [13] states that route protocols are implemented in small networks with a high traffic density because of the constant packet information flow. Below is a description of the principal route protocols.

- DSDV, Destination Sequenced Distance Vector., Elizabeth M. Royer [14], defines it as a "Table Driven" protocol based on the classic Bellman-Ford distribution. This mechanism was improved by dodging routing loops within the network.
  Every network node keeps a table with routing information, including all possible destinations, as well as its possible relay nodes. Therefore, route information will always be available regardless of the existence of the

source node requirement of that information. Each entry is tagged with a sequential number assigned by the target node. This allows the relay nodes to distinguish between a worn path and a new one, thus avoiding routing loops. Tables are updated permanently and sent to the network to maintain consistency, causing high network traffic, which negatively impacts network resources usage. Full dump table update packets are used to improve this issue. This sort of packages carries all routing information and requires multiple Network Protocol Data Units (NPDUs, Relay Nodes). During the network's low traffic periods, packets are occasionally transmitted. Incremental small packets are used only for information that needs to be used by a relay node that has changed since the last full dump into the network.

- WRP, Wireless Routing Protocol. Murthy [15] [16] describes this protocol, which addresses the issue of reaching free or direct links. It is a "Table Driven" protocol that keeps complete information in all network nodes. This model is a typical Route Discovery Algorithm, which in this case, avoids the issue of counting to infinite [17], forcing each node to perform a consistency check with all its neighbors on predecessor node information. This process eliminates loops and provides a quick convergence for route searching when links are broken. Each node must keep four tables:

    1. The distance table shows the number of nodes between source and destination.
    2. The routing table indicates the next relay node.
    3. The cost-link table reflects delays associated with a specific link.
    4. Relay Message List (LMR) table contains a sequential update message number, a relay count, a flag-vector acknowledgment with one entry per neighbor node, and a list of updates sent in the update message.

LMR records the refresh message updates that need to be retransmitted and the neighbor nodes that need to confirm relay, and so on. The algorithm decongests the network's traffic channeling information flow to the appropriate route instead of across the entire system.

Each node sends an update after it has processed the receiving information from its neighbors or when changes are detected in neighbor links. In the case of a broken link between two nodes, each one sends a message to their respective neighbors. Neighbor nodes modify the distance table, and the possibility of new routes through other nodes is verified. The new route is relayed to the source node with information to update tables to re-establish the link.

Each node notices the existence of a neighbor when it receives "acknowledgment" (AKG), among other messages. Inactive nodes must send a "hello" message to ensure connectivity. Otherwise, the resultant link failure will be misinterpreted as a false alarm. When a node receives "hello" from a new node, it joins the routing table, and the routing table sends an update message with the information from the four tables to the new node.

- CGRS *(Cluster head Gateway Switch Routing)*, unlike previous protocols, this is a flat organization. CGRS is hierarchical and uses a multi-hop cluster mobile network with various heuristic schemes. Ciang [18] mentions that with a cluster-type node, a code separation system between clusters, and channel access, it can achieve proper routing and bandwidth distribution. A distributed selection algorithm within the cluster chooses the head node. One drawback is frequent cluster head changes affecting overall protocol performance caused by busy nodes executing the selection process and, therefore, unable to perform their relay node task. Thus, instead of invoking a re-selection method, each time cluster membership changes, the head in the "Least Cluster Change" (LCC) algorithm only changes when two cluster heads come into contact or when a node goes out of range from all other cluster heads.

  CGSR is based on the DSDV protocol,

consequently with the same DSDV high traffic load. However, CGSR includes a modification with an approximation to a hierarchical routing from cluster head node to output gate node (output gate node is a cluster relay node, named by the author) in traffic from source to destination node. Output gate nodes are within the communication range between two or more cluster head nodes. The source node sends a packet to accomplish communication between the source and the destination node, and it is first routed to a cluster head node, which relays the packet to another cluster head node using the relay provided by the output gate node. The process continues until the packet reaches the destination node. When using CGSR, each node must have a cluster membership table where the network cluster head destination nodes store the information. These tables are periodically spread through the DSDV protocol; all nodes update the cluster membership table through the transmission from one of its neighbor nodes. In addition to the cluster membership table, each node must have a routing table to determine the next relay node to reach the destination node. When a packet is received, the node's cluster membership table and cluster routing table identify the closest cluster head node in route, then the routing table determines the next relay node to reach the specified closest cluster head node and transmits the packet to it.

B. Reactive or "On Demand" protocols.

Grady [4] defines this category as protocols that only create routes within the network when a source node demands it. Once a route is established, it is kept by a maintenance procedure until the destination becomes unreachable or the route is no longer needed. Coya Rey [12] mentions that On-Demand protocols fit best in small networks with low nodes and static traffic patterns in a highly mobile system.

Shobana [19] argues that such protocols compared to proactive ones have higher power consumption and a more significant message delay; flexibility in operations is accomplished by reducing route loads considering that no loops form in TDL networks.

- (AODV, Ad Hoc On-Demand Routing Protocol) Taneja [20] mentions that this is a variation of the previously described DSDV protocol. AODV minimizes the system requirement to broadcast the entire network up to the endpoints. Routes among network nodes are not permanent. The protocol searches for routes when required, which are kept active while being used. Taneja also points out the key steps to establish an AODV protocol are the following:

  1) Route creation verifies if there is an established route in the tables. If no path is available, the source node sends a ROUTE Request (RREQ) packet containing the IP address, current sequential number, destination IP address, destination node last sequential number, and emission ID. Sequential numbers control the message timeline. Once RREQ is broadcasted to all neighboring nodes, a time count to wait for response initiates. Upon RREQ reception, each relay node receives the request and prepares a route that is returned to the source node. Once the RREQ packet reaches its destination with the route creation information, it is returned with an RREP (Reply Route) message.
  2) *Search ring expansion technique*. The source node sends an RREQ packet to all neighboring nodes and relays, which successively do the same with their adjacent nodes. RREQ emission control is mandatory in vast networks. To perform this control, the source node uses a search ring expansion technique, which establishes a *time-to-live* (TTL) with an initial defined value. If there is no response during this search period RREQ packet is broadcasted again with an increased TTL value. TTL value will increase progressively until the default threshold is reached, ensuring the RREQ packet is posted to the entire network.
  3) Route Setting. When destination and relay nodes with the route receive an RREQ,

an RREP is created and broadcasted in a single direction towards the source node using the path back to the node from which RREQ information was received. When relay nodes receive an RREP, a new entry for the destination route is set in its route table. When the RREP message reaches the source node, the path from destination to source node is set; therefore, the source node can start transmitting.
4) Route Maintenance, the path between source and destination nodes is kept as long as the source node requires it. Considering that Ad Hoc network nodes are mobile and that source node moves during the active session, the route search process must be performed again to establish a new path between source and destination nodes. Conversely, if the destination node or relay nodes move, the link can be broken. The node where a broken link occurs initiates a string with the route error message (RERR, Route Error) to the affected neighbor node, which consequently propagates the RERR to its predecessor node. This process continues until the RERR message reaches the source node. Once it is received, the source node can stop broadcasting or restart the route search mechanism by sending a new RREQ message if the route is still required.

- DSR, Dynamic Source Routing. Coya Rey [12] defines it as a protocol that bases are routing on the source. Each node has a local cache to store information related to the desired route in the network. There are two possibilities for caching in each node. The first one is the path cache in which each node stores its path to the other node, and binding cache, in which each node adds a link to a graph that represents the node's perspective in the network topology. Links obtained from different routes could form new routes, so the binding cache handles more information than the path cache. Taneja [20] states that this protocol is appropriate for mobile networks requiring relay nodes. The main benefit is that there is no need for a route table because the route is contained in the header of each packet sent. DSR performance is better in a static or low mobility environment. Among its disadvantages is the fact that broken links do not self-repair; this causes the most significant delay in resetting routes, taking more time than a table-based protocol. Another drawback is that each node spends considerable processing time obtaining control route information, even when there is not a destination node. This protocol has two fundamental components:

1) Route Discovery. As mentioned above, each node has a cache where it stores the most recent route searches. When a node wants to send information packets to another node, it must verify its entry in the cache. If there is access, then that route is used to transmit, and the source address is added to the packet. If there is no access while verifying the threshold or timeout has expired in the cache memory, the source node issues a route requirement packet to all neighboring nodes querying about the route to the destination, and it must wait until the path is found.

Meanwhile, the source node could execute other functions, such as forwarding packets. When the request packet reaches any relay node, it is compared to its cache or that of its neighbors to find if the destination route requirement is known or not. In case it is known, the node sends a response packet to the destination node. If unknown, the node will continue sending the same path request packet as when establishing a discovered route; the source node sends information on the destination path. The protocol adds a cache entry for future use; each node keeps the time information since the last cache entry to the actual one to know whether it is recent or not. When a packet reaches a relay node, it checks whether the packet is destined to it or not, in case it is a response packet sent; if not, the packet is forwarded as it is.

2) Maintenance. This process should be able to detect in active route or in the network if the topology has changed in such a way that

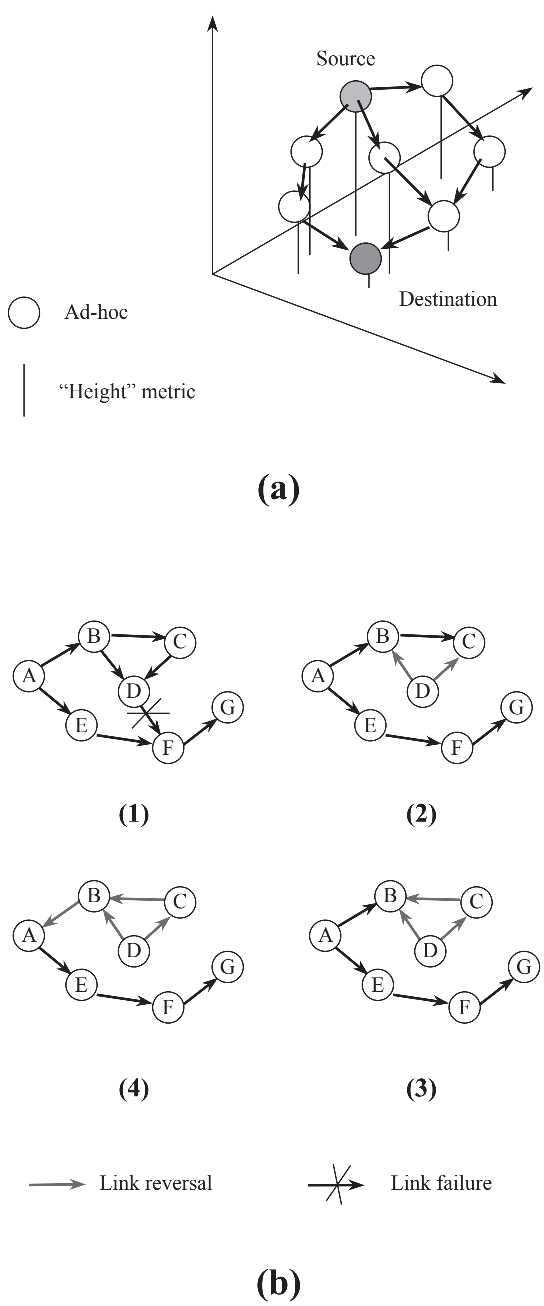
the established route is no longer available or its links do not work. At this point, the node where a fault is detected verifies if another known route to the destination exists; if not, it starts a new route search process. Either way, each node will change the entry path in the cache. The maintenance process works only during the route active time period.

- TORA, Temporally Ordered Routing Algorithm. Royer [14] defines it as a highly adaptive, non-linking, and distributed algorithm, based on the inverted link concept, designed to perform highly dynamic movable networks. Toh [1] describes the TORA protocol in section 5.8, based on the control packets broadcasting, focused on a small group of nodes close to the occurrence of a topological change in the network. The nodes must keep information about the routes of neighboring nodes to achieve this protocol goal. The protocol executes three main activities, searching or discovering the route, maintaining the route, and finally, deleting the route. During the creation and maintenance phase, the protocol uses a metric called "height," which assigns an acyclic direct graph to the destination node. Each link between the nodes sets a specific address above and below, related to the height of its neighboring nodes. Fig. 3 [1], taken from the same section of the Toh book, shows (a) the search process and (b) the maintenance process.

  If a link breaks during the maintenance process while the route is active, a new route discovery process to the destination node initiates, as shown in Fig. 3 part (b). In case of failure of the last descent direction link node, the protocol generates a new height reference, which is propagated to its neighbors. The links must invert to reflect the changes and to adapt to a new height. This also occurs if a node does not find a downlink (i.e., no longer finds neighboring nodes). The time factor is critical in this protocol because the determination of the "Height" metric depends on the logical time or time when a link breaks. TORA assumes that all nodes have synchronized clocks (probably by a GPS clock).

  The metric used by this protocol has five components (1) Logical break time, (2) unique node ID that defines the new height, (3) bit reflection indicator, (4) Propagation order parameter, and (5) unique respective node ID.

Fig. 3. (a) Route Creation, (b) Route maintenance in TORA.



Height is collectively represented by the first three, and a new height is defined whenever a node loses its downlink due to failure. In the deleting phase, this protocol floods the network broadcasting a CLEAR packet (CLR) to clear the invalid routes.

Taneja [20] mentions that this protocol uses arbitrary Height parameters to determine the direction of the link between two nodes, thus obtaining multiple paths for the same destination, none of which is necessarily the shortest. Additionally, when a node discovers that a route is no longer valid, it adjusts its height to the maximum value between neighboring nodes and thus transmits an update packet "UPDATE." If no neighbor nodes with a finite height concerning the destination are present, then it will start the process of discovering a new path that was already described.

Taneja [20] states that some of the benefits of TORA are the control of multiple routes between source and destination nodes, as well as the short time required to re-establish communication when a failure occurs by switching to another path. One of its disadvantages is that it involves clock synchronization among all network nodes. In order for this to work, it presumes that status detection, neighborhood discovery, packet delivery, and address resolution capabilities are easily accessible.

C. Hybrid Protocols.

According to Coya Rey [12], Hybrid protocols mix proactive and reactive protocols. This type of routing is performed by "cluster," i.e., intradomain and interdomain simultaneously. Proactive protocols serve for communication inside a cluster, and reactive protocols, for communication between clusters. Zone-based or cluster protocols are used in large networks with many nodes. Some examples of these protocols are the Zone-Based Routing Protocol (ZRP) and the Adaptive, Hybrid Adaptive Routing Protocol (SHARP), among others.

Zone-Based Routing Protocol (ZRP). According to Toh [1], ZRP uses the merits of reactive and proactive protocols. Routing zones are similar to a cluster, but each node acts as a zone head and, at the same time, as a member of other clusters or zones.

Zones can overlap; each node specifies a radius in terms of radius nodes; the selection of the zone size has a significant impact on the performance of the Ad Hoc network.

Coya Rey [12] mentions that in order to build a zone, each node that is one hop away and could be reached directly has to be identified. The "Neighbor Discovery Protocol" (NDP) is responsible for controlling and searching routes and indicating when a route fails. This protocol broadcasts a query packet with the message "HELLO" at a specific interval. When zone nodes identify it, route tables are modified and updated.

The radius of length x determines zone dimensions, x indicates the number of hops from the source node to the zone edge, and it is also tied to the node emission power and other parameters. The protocol performance depends on the length of the x-radius that determines the zone area: small radius for small zones in dense networks that have high mobility nodes, and larger radius for more extensive areas, dispersed systems, and low mobility nodes.

Toh, [1] in section 5.12 states that ZRP handles three sub-protocols, (a) table-driven, called IARP Intrazonal Routing Protocol, (b) Interzone Routing Protocol (IERP Interzone Routing Protocol), and (c) Border cast Resolution Protocol (BCRP). Implemented IARP uses the "Link State" or Routing Distance Vector, across the border in the routing zone disseminating information. IARP depends on the NDP protocol to detect the presence of neighboring nodes, therefore node-link connectivity, if any. Its primary mission is to ensure that each node in the zone has a consistently updated routing table that reflects the information of how each node in the zone is able to reach other nodes. IARP relies on edge nodes to execute on-demand routing to find information about nodes outside their zone. IERP uses the BCRP protocol in replacement of the query message "HELLO" when propagating within another zone.

According to Haas [36], one consideration about ZRP is that it handles different protocols according to zones, and this affects the performance efficiency of interzonal communication, and the route search can be unstable and challenging. Without proper query control, ZRP can have reduced performance than typical protocols based on "flooding." Inside a zone, a route failure due to node mobility is treated with a proactive protocol; the node reports the loss to every zone node, which, upon information reception, update their route tables. If route failure is due to an edge node or a different zone node, route repair runs like a new route search. In the worst case scenario, the failure route message is sent to the source node.

The last lines describe the protocol operation and compare the algorithm's main characteristics. Now some differences will be exhibited. Time complexity is smaller in WPR than in DSDV because the latter informs only the neighboring nodes about the link status changes when a link fails. When additional links are established, the "HELLO" packet is used as a presence indicator to allow the entry to update the routing table affecting the neighboring nodes exclusively.

In the CGSR, the routing performance depends on the status of specific nodes (cluster heads, output nodes, or normal nodes). Link failure time complexity is associated with a cluster head and is higher than in the DSDV protocol due to the need for extra time to select a new cluster head. In the same way, this applies to the selection of new nodes links that are associated with cluster heads.

In terms of communications complexity, since the DSDV, CGRS, and WRP use shorter Path Distance Vector protocols, all of them have the same degree of complexity during link breakouts and additions.

Reactive Protocols comparison in Table 4 shows that the AODV protocol, like the DSR, use the same procedure to find a source to destination node path. However, it differs from the fact that DSR has a higher load in each used packet to carry established route information. In contrast, the AODV only carries the destination route information. This also happens with packet responses and in-memory loading of each protocol. AODV is the only compared protocol that can perform multi-broadcast.

The requirement of link symmetry between nodes is a drawback of the AODV protocol being unable to use asymmetric links routes, unlike DSR, which is able to use asymmetric links when symmetric ones are not available.

The DSR [23] protocol performs best on moderate mobility nodes networks concerning packet transmission latency, and this presumption provides a small network diameter, which allows all nodes to become receiving nodes. Hence, the network management software receives any packet without a filter or restriction provided by the destination address.

The DSR does not perform periodic broadcasting requirements saving bandwidth and power consumption. Therefore, this protocol is not overloaded when there are no network topology changes. Additionally, it allows each node to keep information of all routes established to the destination node in its cache. Thus, when a link is broken, relay nodes can check their cache for another path. If not found, the protocol invokes the algorithm to find a new route. In the DSR, the recovery of a route is faster than in other algorithms. However, due to the DSR small diameter, it is not scalable to vast networks.

The TORA is an "inverted link" type algorithm, according to Park [24]. This protocol is best suited to large networks with a dense node population. DSR and TORA are the only two protocols capable of establishing more than one route between the source and destination nodes. Rebuilding routes is not necessary until all possible paths have been considered valid. Therefore, bandwidth is retained. Another advantage of TORA is the multicast capability, which, unlike in AODV, is

Table 2. Comparison of Reactive Protocols.

Metric	PERFORMANCE AREAS		Reactive PROTOCOLS		
			AODV	**DSR**	**TORA**
I. Package Sent Ratio	1	Network mobility		Moderate related to latency	High mobility
	2	Route type.	On-demand.	Multiple.	Multiple.
		Shorter/more congested ratio	Always selects the least congested route.		
		Complexity in time	Initialization 0(2d), fails 0(2d)	Initialization 0(2i) Post fails 0(2d) or 0*.	Initialization 0(2i) Post fails 0(2d)
		Complexity communications.	0(2N)	0(2N)	Initialization 0(2N) Post fails 0(2x)
	3	Network and route information Availability	Available when needed	Available when needed	Available when needed
II. TDL Delays between the source node and the destination node.	4	Delays and latency	Higher message delay than proactive in the route discovery process,	Higher message delay than proactive in the route discovery process,	Higher message delay than proactive in the route discovery process,
	5	Bandwidth Consumption	Higher than usual due to the issuance of the HELLO message.	Low consumption	Just as the DSR is smaller
	6	Route Metric	Freshest and shortest path	Shortest path	Shortest path
		Route Maintenance	Route Tables	Route caches	Route Tables
		Multi-route possibilities	No	Yes	Yes
		Route Reconfiguration	Delete route; notify the source	Delete route; notify the source	Link reversal; route repair
		Periodic route update	Not Required	Not Required	Not Required
III. Loading in messages	7	Network size and number of nodes	Small, few nodes	Small, non-scalable for large networks, few nodes	Small, It handles high node density
	8	Traffic associated load. frequency TX/RX	Static	Static	Static
	9	Multicast Capability	Yes, even motion nodes.	Yes	No, but, supports through LAM (*4),
	10	Routing Philosophy and Critical Nodes	Flat, No	Flat, No	Flat, No
	11	Message load	It does not set additional loads on the network	Proportional to the distance of the link/ carries all the complete information of the route / s	
		Reaction to link failures	Quickly responds to topologic changes.	Does not repair the links locally reset is longer than proactive	Quickly, but if it has to restart, the discovery process is the slowest.
		Net Saturation	Saturated due to the flooding technique.		
		Signaling traffic generated	Grows with the increasing mobility of active routes		
	12	TX update Frequency and Updates TX to:	N/A	N/A	N/A

IV. Energy consumption	13	Power consumption		Hight power consumption	
V. General features that do not affect performance	14	Exclusively dedicated capacity of relay nodes	Not simultaneous due to nodes detecting emissions between each other.		
	15	Clock synchronization			Needs Synchronization time
	16	Loop free	Yes	Yes	Yes

Table 3. Comparison of Proactive Protocols.

Metric	PERFORMANCE AREAS		Reactive PROTOCOLS		
			DSDV	CGRS	WRP
I. Package Sent Ratio	1	Network mobility		High density	
	2	Route type.	The ones on the TABLE	The ones on the TABLE	The ones on the TABLE
		Shorter/more congested ratio	Shorter route selection	Shorter route selection	Shorter route selection
		Complexity in time	0(d)	0(d)	0(h), Low compared to DSDV
		Complexity in communications.	0(x = N)	0(x = N)	0(x = N)
	3	Network and route information Availability	Nodes have route information in two tables regardless of need. (*1).	Nodes have route information in two tables regardless of need. (*1). It is hierarchical, and a node at some point cannot be a relay node.	Nodes have route information in four tables regardless of need. (*1).
II. TDL Delays between the source node and the destination node.	4	Delays and latency		Less delays than reactive	
	5	Bandwidth Consumption	Can be higher because of the use of tables	Can be higher because of the use of tables	High because of the need to be sending Hello packets
	6	Route Metric	Freshest and shortest path	Shortest path	Shortest path
		Route Maintenance	Route Tables	Route Tables	Route Tables
		Multi-route possibilities	Yes	Yes	Yes
		Route Reconfiguration		No need route already reconfigured in the tables.	
		Periodic route update	Required	Required	Required
III. Loading in messages	7	Network size and number of nodes	High- permanent route availability limit the number of nodes that can connect to the network grows in an O(n2) order.	Small, few nodes can be connected	High due to the permanent availability of routes.
	8	Traffic associated with load and frequency of emission and reception		Inefficient due to the need to be periodically transmitting a network update regardless of how many times the network topology changes	
	9	Multicast Capability	No	No (4*) does it through a sub-algorithm	No

	10	Routing Philosophy and Critical Nodes	Flat, No	Hierarchical,	Flat (*4), No
	11	Message load		Equal to the DSDV/ WRP, the load is even higher because it requires maintaining four tables.	
		Reaction to link failures	The updating process is slow because it has a lot of information on each node, significant when the link is dropped. / DSDV Requires constant updating as there are no changes in the topology.		
		Net Saturation	Not saturated		
		Signaling traffic generated	Higher than reactive routing		
	12	TX update Frequency and Updates TX to:	Periodically and as needed. Neighbors	Periodically and Neighbors and cluster head	N/A Periodically and as needed. Neighbors
IV. Average energy consumption	13	Power consumption	Moderate power consumptions, eventually high		
V. General features that do not affect performance	14	The exclusively dedicated capacity of relay nodes			
	15	Clock synchronization	No need	No need	No need
	16	Loop free.	Yes	Yes	Yes, but not instantaneous

not incorporated in the essential operation but performed by means of a dedicated sub-algorithm called Lightweight Adaptive Multicast Algorithm (LAM). TORA and LAM enable the multicast capability. TORA depends heavily on node clock synchronicity. Network nodes must have a GPS or any other mean to control time to allow performance.

Route recovery is not as expeditious in TORA as in other protocols due to potential oscillations within this period, which can cause long delays until a new route is determined.

Proactive protocols are based on routing tables that store information for all possible routes demanding this information to be broadcasted continuously or table updates being issued. These activities require higher power consumption, broader bandwidth, and produce considerable delays. These demands provide the advantage of more robust links that remain without breakouts for much longer.

Information management based on demand corresponds to reactive protocols, so their efforts are materialized only when necessary, either to establish a new route or to repair a broken link. Reactive protocols' advantages are low power consumption, less data traffic improving bandwidth exploitation. However, unlike proactive protocols, these routes are less robust, and rebuilding routes takes much longer, causing delays or link loss. Finally, this comparison will be analyzed later for benchmarks and the simulation process to meet the main objective of this work, which is to recommend as far as possible the best protocol to be implemented in the CTDL.

Conclusions and future work

In reactive protocols, broadband usage is optimized because of less load on messages. On-demand traffic, no requirements for continuous updates, and low traffic assure the protocol's excellent performance. Thus, reactive protocols perform better than proactive ones in the update and link-breaking recovery processes since the proactive ones require constant table updating, and therefore information traffic becomes congested. Among reactive protocols, TORA and AODV have the multicast capability, while among proactive protocols, only the CGRS has this capability through a secondary algorithm. Bandwidth consumption is lower, especially in TORA and DSR, because the messages are only sent on demand, in contrast with them being sent continuously in proactive protocols.

All the routing protocols keep links between nodes as long as route information is maintained; however, Table-Driven protocols work better because the information is always available. Considering the aforementioned theoretical performance algorithms, it can be concluded that proactive protocols have a lower delay in messaging. Another advantage of proactive protocols is that they usually select the shortest path, which is the most powerful to create stronger links. Regarding node quantity, relatively few protocols have improved performance, particularly the DSDV protocol.

There are many features of routing protocols that are not actually usable by the network posed in this maritime scenario, as well as others that would not differ in their implementation, such as power usage because the participating nodes have a constant power supply. Both reactive and proactive protocols perform well in small networks of moderate traffic and low density, but as the system grows in density and traffic, advantages and disadvantages show up. In terms of latency, routing protocols would be well implemented on the network because actual usage dynamics allows delays for up to two minutes without being critical. The CTDL implemented features clock synchronization via GPS used to determine node position and media access control when required. This capability would be available if the TORA protocol is implemented. Regarding network size for simplicity purposes, flat and non-hierarchical protocols should be implemented.

This study allows us to infer that reactive protocols might work better than proactive protocols in CTDL, mainly because of bandwidth consumption. This issue is critical because of the hardware limitations mentioned in the CTDL for maritime scenarios. Hence, according to the analysis for this type of reactive protocol (On-Demand), the DSR might perform better.

Validation of this preliminary study employing a simulation tool that allows for adjustment of results with the obtained data is required as future work.

Bibliography

[1] C.-K. TOH, Ad Hoc Mobile Wireless Networks, Protocols and Systems, Upper Saddle River, New Jersey: Prentice-Hall, 2002.

[2] S. M. L. S. M. T. GUSTAVO PEREZ VALDEZ, "Desarrollo de un Enlace de Datos Tactico, Fsae 1: Prototipo," COTECMAR, Cartagena, 2012.

[3] I. BOLT BERANEK AND NEWMAN, "A History of the ARPANET," DARPA, Arlington, Virginia, 1981.

[4] J. P. O. GRADY AND A. MCDONALD, "State of the Art: Ad Hoc Networking," *M-Zones Deliverable 1*, vol. State of Art Surveys, no. 2, pp. 16-26, Mayo 2003.

[5] C. L. G. JR., "Data Link Communications Tactical Air Command and Control Systems," *IEEE JOURNAL SELECTED AREAS IN COMMUNICATIONS*, vol. SAC 3, no. 5, pp. 779-790, 1985.

[6] J. M. GOMEZ T., W. A. CASTRO C, G. PEREZ V, S. MARRUGO LL. AND J. VILLEGAS D, "Codesarrollo de un Sistema De red Tactica Naval .....," COTECMAR, Cartagena, 2015.

[7] B. TANG, BAOLIU YE, L. SANGLU, G. SONG AND I. STOJMENOVIC, "Latency-optimized Broadcast in Mobile Ad Hoc Networks without Node Coordination," in *MobiHoc 2014*, Philadelphia, PA, USA, 2014.

[8] K. A. JAGADEV, K. B. PATTANAYAK, K. M. MISHRA AND M. NAYAK, "Power and Delay Aware On-Demand Routing For Ad Hoc Networks," *IJCSE International Journal of Computational Science and Engineering*, vol. 02, no. 04, pp. 917-923, 2010.

[9] M. GERLA, L.-J. CHEN, Y.-Z. LEE, B. ZHOU, J. CHEN, G. YANG, AND S. DAS, "Dealing with node mobility in Ad Hoc wireless. Network," UCLA, Computer Science Department, Los Angeles, California, 2005.

[10] NORTHROP GRUMMAN, LINK 22 Guidebook Overview, San Diego, California: Space & Mission Systems Corp., 2010, p. 120.

[11] P. KUOSMANEN, "Classification of Ad Hoc Routing Protocols," Helsinki.

[12] L. COYA REY, T. O. LEDESMA QUIÑONES AND W. BALUJA GARCIA, "Protocolos de enrutamiento aplicables a redes MANET," *REVISTA TELEM@TICA*, vol. 13, no. 3, pp. 59-74, 2014.

[13] M. VENKAT AND N. KASIVISWANATH, "Routing Protocols for Wireless Mesh Networks," *International Journal of Scientific & Engineering Research*, vol. 12, no. 8, 2011.

[14] C.-K. T. ELIZABETH M. ROYER, "A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks," *IEEE Personal Communications*, vol. 6, no. 2, pp. 46-55, April 1999.

[15] S. MURTHY AND J. GARCIA-LUNA-ACEVES, "A Routing Protocol for Packet Radio Networks," *Proceedings of ACM First International Conference on Mobile Computing & Networking MOBICOM95*, Noviembre 95.

[16] S. MURTHY AND J. GARCIA-LUNA-ACEVES, "An efficient Routing Protocol for wireless Network," *ACM Mobile Networks and App. J.*, no. Special on Routing In Mobile Communication Network, pp. 97-183, Octubre 1996.

[17] A. TANENBAUM, Computer Networks, vol. 3, Englewood, New Jersey: Prentice-Hall, 1996, pp. 357-358.

[18] C. -C. CHIANG, "Routing In Clustered Multihop, Mobile Wireless Networks with Fading Chanel," in *IEEE SICON 97*, Singapore, April 1997.

[19] M. SHOBANA AND S. KARTHIK, "A Performance Analysis and Comparison of various Routing Protocols in MANET," in *Proceedings International Conference on Pattern Recognition, Informatics and Mobile Engineering*, Tamilnadu, India, 2013.

[20] S. TANEJA AND A. KUSH, "A Survey of Routing Protocols in Mobile Ad Hoc Networks," *International Journal of Innovation and Technology*, vol. 1, no. 3, pp. 279-285, August 2010.

[21] M. SHOBANA AND S. KARTHIK, "A Performance Analysis and Comparison of various Routing Protocols in MANET," in *International Conference on Pattern Recognition, Informatics and Mobile Engineering (PRIME)*, Tamilnadu, India, 2013.

[22] H. T. DUYEN, W. BENJAPOLAKUL AND P. D. MINH, "Performance evaluation and comparison of different ad hoc routing protocols," *Computer Communications*, pp. 2478-2496, 4 May 2007.

[23] D. JOHNSON AND D. MALTZ, "DYNAMIC SOURCE ROUNTING IN AD-HOC WIRELESS NETWORKS," in *Mobile Computing*, T. Imielinski, and H. Korth, Kluwer, 1996.

[24] V. PARK AND M. CORSON, "A Highly Adaptive Distributed Routing Algorithm for Mobile Wireless Networks," in *INFOCOM 97*, Kobe, Japan, 1997.

[25] S. MURTHY AND J. GARCIA -LUNA-ACEVES, "Loop-Free Internet Routing Protocol Using Hierarchical Routings tress," in *INFOCOM '97*, Kobe, Japan, 1997.

[26] C.-C. CHIANG, M. GERLA, AND L. ZHANG, "Adaptative Shared Tree Multicast in Mobile Wireless Networks," in *GLOBECOM 98*, Sidney, Australia, 1998.

[27] L. JI AND M. CORSON, "A lightweight Adaptive Multicast Algorithm," in *GLOBECOM 98*, Sidney, Australia, NOV-1998.

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[1] J. K. Author, "Title of paper," in *Unabbreviated Name of Conf.*, City of Conf., Abbrev. State (if given), year, pp. xxx-xxx.

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FTP

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[1] J. K. Author. (year). Title (edition) [Type of medium]. Available FTP: Directory: File:

Example:
[1] R. J. Vidmar. (1994). *On the use of atmospheric plasmas as electromagnetic reflector*s [Online]. Available FTP: atmnext.usc.edu Directory: pub/etext/1994 File: atmosplasma.txt.

WWW

Basic form:
[1] J. K. Author. (year, month day). Title (edition) [Type of medium]. Available: http://www.(URL)

Example:
[1] J. Jones. (1991, May 10). Networks (2nd ed.) [Online]. Available: http://www.atm.com

E-Mail

Basic form:
[1] J. K. Author. (year, month day). Title (edition) [Type of medium]. Available e-mail: Message:

Example:
[1] S. H. Gold. (1995, Oct. 10). *Inter-Network Talk* [Online]. Available e-mail: COMSERVE@ RPIECS Message: Get NETWORK TALK

E-Mail

Basic form:
[1] J. K. Author. (year, month day). Title (edition) [Type of medium]. Available Telnet: Directory: File:

Example:
[1] V. Meligna. (1993, June 11). *Periodic table of elements* [Online]. Available Telnet: Library. CMU.edu Directory: Libraries/Reference Works File: Periodic Table of Elements

Patents

Basic form:
[1] J. K. Author, "Title of patent," U.S. Patent x xxx xxx, Abbrev. Month, day, year.

Example:
[1] J. P. Wilkinson, "Nonlinear resonant circuit devices," U.S. Patent 3 624 125, July 16, 1990.

Standards

Basic form:
[1] Title of Standard, Standard number, date.

Example:
[1] IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.

Theses (M.S.) and Dissertations (Ph.D.)

Basic form:
[1] J. K. Author, "Title of thesis," M.S. thesis, Abbrev. Dept., Abbrev. Univ., City of Univ., Abbrev. State, year.

Example:
[1] J. O. Williams, "Narrow-band analyzer," Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, 1993.

Unpublished
These are the two most common types of unpublished references.

Basic form:
[1] J. K. Author, private communication, Abbrev. Month, year.
[2] J. K. Author, "Title of paper," unpublished.

Examples:
[1] A. Harrison, private communication, May 1995.
[2] B. Smith, "An approach to graphs of linear forms," unpublished.

Periodicals
NOTE: When referencing IEEE Transactions, the issue number should be deleted and month carried.

Basic form:
[1] J. K. Author, "Name of paper," *Abbrev. Title of Periodical*, vol. *x*, no. x, pp. *xxx-xxx*, Abbrev. Month, year.

Examples:
[1] R. E. Kalman, "New results in linear filtering and prediction theory," J. Basic Eng., ser. D, vol. 83, pp. 95-108, Mar. 1961.

References
NOTE: Use *et al*. when three or more names are given.

References in Text:
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as shown by Brown [4], [5]; as mentioned earlier [2], [4]–[7], [9]; Smith [4] and Brown and Jones [5]; Wood et al. [7]

or as nouns:

as demonstrated in [3]; according to [4] and [6]–[9].

References Within a Reference:
Check the reference list for ibid. or op. cit. These refer to a previous reference and should be eliminated from the reference section. In text, repeat the earlier reference number and renumber the reference section accordingly. If the ibid. gives a new page number, or other information, use the following forms:

[3, Th. 1]; [3, Lemma 2]; [3, pp. 5-10]; [3, eq. (2)]; [3, Fig. 1]; [3, Appendix I]; [3, Sec. 4.5]; [3, Ch. 2, pp. 5-10]; [3, Algorithm 5].

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