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Editorial Note

Cartagena de Indias, July 31st, 2022.

Receive a very special greeting at the beginning of this new edition of our Ship Science and Technology Journal, after a dynamic semester in which the reactivation of research activities, technological development and the permanent search for innovation have marked the course of our action.

In these first six months of 2022, COTECMAR has developed processes aimed at fulfilling its corporate MEGA, thanks to the completion of the construction phase of our Marine Scientific Research Vessel and the progress made in the selection process of the technological partner for the Surface Strategic Platform (PES); milestones of the utmost importance for Colombian naval engineering, among other achievements.

Added to the above is the renewal of our recognition as a Technological Development Center for a maximum period of five years, recently received from the Ministry of Science, Technology and Innovation of Colombia; fact that fills us with pride and commits us even more to continue with the work of promoting the development of the naval, maritime and river sector of our country.

For this edition of the magazine we include topics such as: the speed and heading control system for an Unmanned Surface Vehicle -USV, the pedagogical strategy for the Generation of Capacities in the Development of Unmanned Surface Vehicles -USVs., the numerical study for the estimation of the hydrodynamic coefficients of current drag in maneuvers of assistance in port (dock) for frigates of the Colombian Navy by means of CFD, and finally, an analysis of the historical behavior of purchases of goods and services in the projects of repair and maintenance of COTECMAR – Bocagrande plant in the last five years.

I take advantage of this edition to, from now on, invite the entire scientific community to our eighth edition of our International Congress of Naval Engineering CIDIN 2023, to be held in our city between March 8 and 10, 2023.

At COTECMAR, "We Moving Forward"

Cordially,

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

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Nota Editorial

Cartagena de Indias, 31 de julio de 2022

Reciban un muy especial saludo al inicio de esta nueva edición de nuestra revista Ciencia y Tecnología de Buques, luego de un semestre dinámico en el cual la reactivación de las actividades de investigación, desarrollo tecnológico y búsqueda permanente de la innovación, han marcado el derrotero de nuestro accionar.

En estos primeros seis meses del 2022, COTECMAR ha desarrollado procesos orientados al cumplimiento de su MEGA corporativa gracias a la culminación de la fase constructiva de nuestro Buque de Investigación Científica Marina y a los avances en el proceso de selección del socio tecnológico para el proyecto país de la Plataforma Estratégica de Superficie; hitos de máxima importancia para la ingeniería naval colombiana, entre otros logros.

A lo anterior se suma la renovación de nuestro reconocimiento como Centro de Desarrollo Tecnológico por el período máximo de cinco años, recibido recientemente de parte del Ministerio de Ciencia, Tecnología e Innovación de Colombia; hecho que nos llena de orgullo y nos compromete aún más en continuar con la labor de impulsar el desarrollo del sector naval, marítimo y fluvial de nuestro país.

Para esta edición de la revista incluimos temáticas tales como: el sistema de control de velocidad y rumbo para un Vehículo de Superficie No Tripulado -USV, la estrategia pedagógica para la Generación de Capacidades en el Desarrollo de Vehículos de Superficie No Tripulados – USVs., el estudio numérico para la estimación de los coeficientes hidrodinámicos de arrastre de corriente en maniobras de asistencia en puerto (muelle) para fragatas de la Armada Colombiana mediante CFD y finalmente, un análisis del comportamiento histórico de compras de bienes y servicios en los proyectos de reparación y mantenimiento de COTECMAR – planta Bocagrande en los últimos cinco años.

Aprovecho esta edición para, desde ya, invitar a toda la comunidad científica a nuestra octava edición de nuestro Congreso Internacional de Ingeniería Naval CIDIN 2023, a desarrollarse en nuestra ciudad entre el 8 y el 10 de marzo próximos.

En COTECMAR, “Seguimos Avante”

Cordialmente,

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

Speed and Heading Control System for an Unmanned Surface Vehicle - USV

Sistema de control de velocidad y rumbo para un Vehículo de Superficie No Tripulado -USV

DOI: https://doi.org/10.25043/19098642.231

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Abstract

This paper presents the results obtained from the design of a speed and heading control system for the platform component of an unmanned surface vehicle (USV) technology demonstrator, using PID controllers. A description of the vehicle technology demonstrator used for the implementation of the system is presented, as well as the tests performed to obtain the dynamic models of the platform component of the USV technology demonstrator, the calculations of the controllers and the navigation tests that validate the performance of these controllers. All the above as a result of the joint research process between the Naval Cadet School "Almirante Padilla" and COTECMAR, with the support of the Naval NCO School "ARC BARRANQUILLA" and financed by the Colombian Navy through Minciencias.

Key words: Unmanned Surface Vehicle, PID controllers, speed and heading control system.

Resumen

Este artículo presenta los resultados obtenidos a partir del diseño de un sistema de control de velocidad y rumbo para el componente de plataforma de un demostrador de tecnología de un vehículo de superficie no tripulado (USV), utilizando controladores PID. Se presenta, en primera instancia, una descripción del demostrador de tecnología del vehículo utilizado para la implementación del sistema, además se presentan las pruebas realizadas para obtener los modelos dinámicos del componente de plataforma del demostrador de tecnología de un USV, los cálculos de los controladores y las pruebas de navegación que validan el funcionamiento de dichos controladores. Todo lo anterior como resultado del proceso de investigación conjunta entre la Escuela Naval de Cadetes “Almirante Padilla” y COTECMAR, con el apoyo de la Escuela Naval de Suboficiales “ARC BARRANQUILLA” y financiado por la Armada Nacional de Colombia a través de Minciencias.

Palabras claves: Vehículo de Superficie no Tripulado, controladores PID, sistema de control de velocidad y rumbo.

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Introduction

The use of Unmanned Vehicles for naval applications is gaining more and more importance. This is why worldwide different naval platforms with these characteristics have already been developed and presented. A review of some of these vehicles is presented by *(Jinyeong, et al., 2017)*. But it is necessary to point out that none of these developments is Colombian. This means that if the Colombian Navy decides to use this technology by acquiring any of these prototypes, it will depend technologically on the manufacturer.

With the intention of reducing this technological dependence, the Naval Cadet School "Almirante Padilla" has been working on a navigation control system for this type of vessels. Initially with the development of undergraduate projects oriented to this topic, and later with the execution of research projects financed by the Colombian Navy through Minciencias.

Thus, projects such as the one presented by *(Ochoa, et al., 2013)* worked on the identification of the hydrodynamic coefficients of a small prototype developed at ENAP which they called "ENAP UNO". On this same prototype *(Cardona, et al., 2014)* developed their degree project on the adjustment of the coefficients of the NOMOTO model to the dynamics of the USV.

Subsequently, in 2015 ENAP received two USV prototypes called "SÁBALO" with which it boosted its progress in the subject and continued in the development of this line of research. Degree projects such as the one carried out by (*Correa, et al., 2017)* who worked on the control of PTZ cameras remotely to be implemented in the USV and also implemented a telemetry system for the *(Camacho, 2017)* implemented a telemetry system for monitoring the navigation angles and geographical position of the prototype.

All of the above was the fundamental input for the formulation and subsequent securing of resources for the execution of project No. 64723. This project developed the navigation control system for the aforementioned prototypes. This, in turn, led to the obtaining of resources for the execution of project No. 75836, a project that is financing the optimization of the communications system and the control station together with its integration to a tactical data system. It is the latter that has given rise to the writing of this article.

The progress made so far on the navigation control system, which continues to be optimized with the execution of this latest project, will be presented.

Test prototype

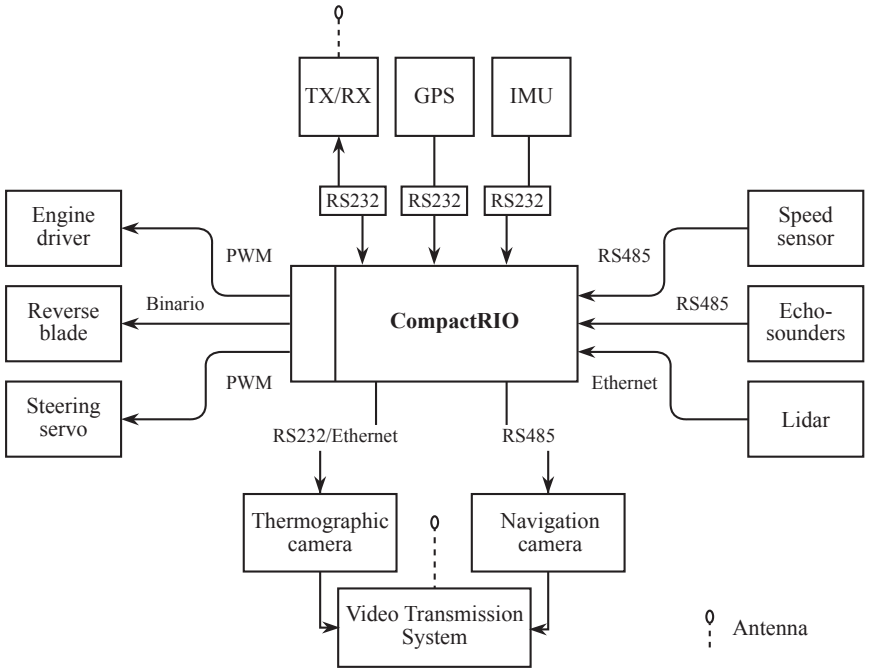
Fig. 1. Test prototype.

The test prototype consists of a fiberglass monocoque platform with four main cavities. These are intended to house the control system, the battery bank and the propulsion system. The bulkheads separating these cavities are made of wood covered with carbon fiber, and the rest of the volume of this filled with polypropylene. This is to guarantee the buoyancy of the boat even in the event of an accident. An image of the prototype is shown in Fig. 1.

The USV consists of a jet propulsor driven by an electric motor to give speed to the jet and a steering nozzle to turn it. The overall dimensions of the platform are presented as listed in Table 1.

The prototype has the necessary sensors and actuators to implement the navigation control system as shown in Fig. 2. The prototype has a Tx/Rx through which the control signals can be sent to the platform and the platform can send the

Fig. 2. USV on-board control system.



Source: Own

Table 1. Main Characteristics of the USV.

Feature	Measure
Length	245 cm
Beam width	89.6 cm
Fretwork	15 cm
Bow strut	30 cm
Stern Strut	38 cm
Weight	117 kg Approx
Speed	9 Approx

telemetry to the control station. For the purposes of this work, the control station was implemented in a computer equipped with a second Tx/Rx to complete the data link.

The entire system on the platform is based on a single processing core where all the instrumentation signals are concentrated and from where all the actuators of the platform are manipulated through the aforementioned data link.

Control System

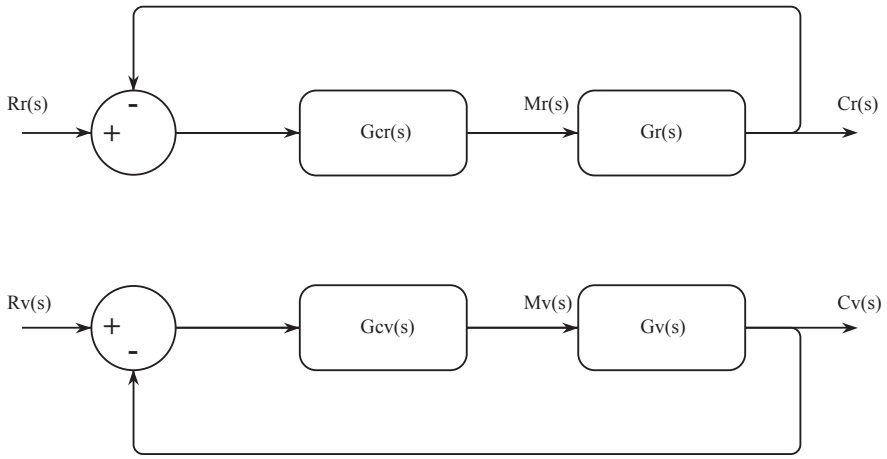
The control system is based on two control loops. One loop manipulates the engine power to control the USV speed, while the second control loop is in charge of manipulating the thruster nozzle to control the USV heading. Fig. 3 presents the control scheme to be implemented.

In Fig. 3, the upper control loop will be in charge of heading control while the lower loop will be in charge of speed control.

The "reference", or "set point", signals Rr(s) and Rv(s) come from the control station via the aforementioned data link while the Gcr(s) and Gcv(s) controllers will be programmed in the USV processing core.

The Gr(s) and Gv(s) Models represent the behavior of the vessel for both heading and speed, mathematical models that were obtained from the navigation tests that were performed.

Fig. 3. Control scheme.



The controllers to be used in both the speed loop and the heading loop are PID controllers.

Navigation tests

The navigation test was performed by executing the following steps.

- USV in Initial conditions. This is propulsion and rudder at 0%.
- Phase 1: With rudder = 0% performs one step step in propulsion
- Phase 2: Once the USV has stabilized in speed, perform a rudder step.

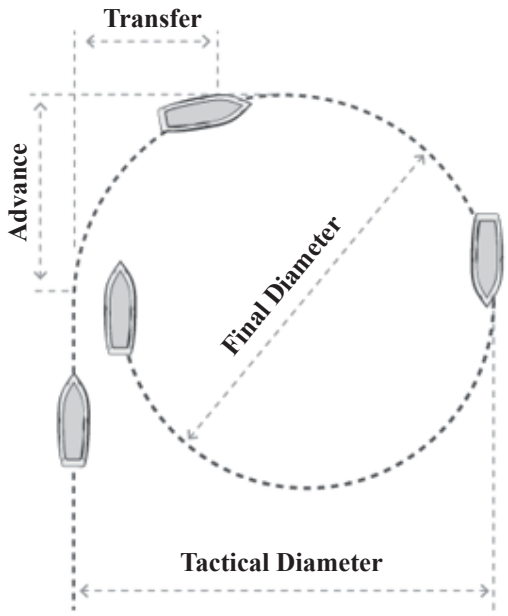
Fig. 4 outlines the trajectory that the USV was to describe during the test. The design of this test was based on the IMO Standard for Ship Maneuverability, presented in Resolution MSC.137(76) adopted on December 4, 2002. *(International Maritime Organization, 2002).*

This test made it possible to obtain the speed model achieved with the measurements during the first phase of the test and the turning model during the second phase of the test.

Controller tuning

For speed controller tuning, the minimum error integral tuning technique optimized for changes in the reference was implemented.

Fig. 4. Evolutionary Circle test (Taken from EscolaPort).



This technique is based on a first order plus dead time model as shown in equation 1. Where k corresponds to the process gain, t_o corresponds to the dead time and τ corresponds to the time constant.

$$G(S) = \frac{k\, e^{-t_0 S}}{\tau s + 1} \tag{1}$$

The values that fit this model to the behavior of the USV will be presented in the results section.

The controller parameters were calculated using equations 2 to 4.

$$K_c = \frac{0.965}{k}\left(\frac{t_0}{\tau}\right)^{-0.855} \quad (2)$$

$$\tau_i = \frac{\tau}{0.796 + 0.147\left(\frac{t_0}{\tau}\right)} \quad (3)$$

$$\tau_d = 0.308\,\tau\left(\frac{t_0}{\tau}\right)^{0.9292} \quad (4)$$

These equations are optimized for the best Integral Time Weighted Absolute Error (ITAE) in the face of a reference change. *(Smith, et al., 1997)*. Other tuning techniques that were explored are presented in *(Alfaro, 2002)*.

The parameters of the Heading controller were calculated using Dahlin Synthesis. *(Smith, et al., 1997)*. This model is the same as the one presented in equation (1) but with $t_o = 0$. Equations 5 and 6 present the calculation for a PI controller.

$$k_c = \frac{\tau}{k\tau_c} \quad (5)$$

$$\tau_i = \tau \quad (6)$$

Where τ_c is the time constant of the response expected by the system with the implemented control loop.

Results

Navigation Tests

The navigation tests were carried out in a 50mx25m pool with a minimum depth of 1.5m and a maximum depth of 2.5m, with the water recirculation pumps off. Performing the tests in this way guarantees that the results will not be affected by transverse currents that could affect the trajectory of the boat and present deviations that are not due to the dynamics of the boat.

Fig. 5 shows one of the results obtained in phase 1 of the navigation tests. This test presents the velocity variation starting at instant $t = 0$, which is the instant at which a 45% CO (Controller

Fig. 5. Velocity Response.

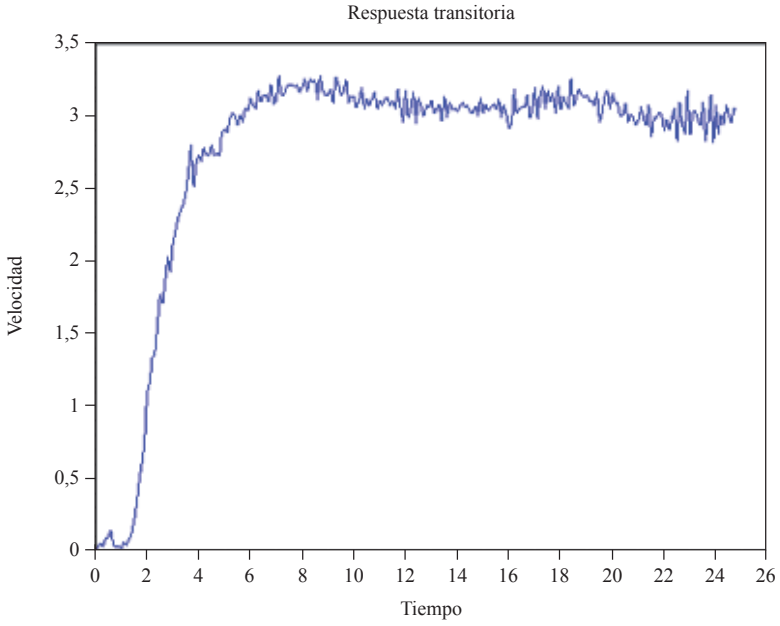
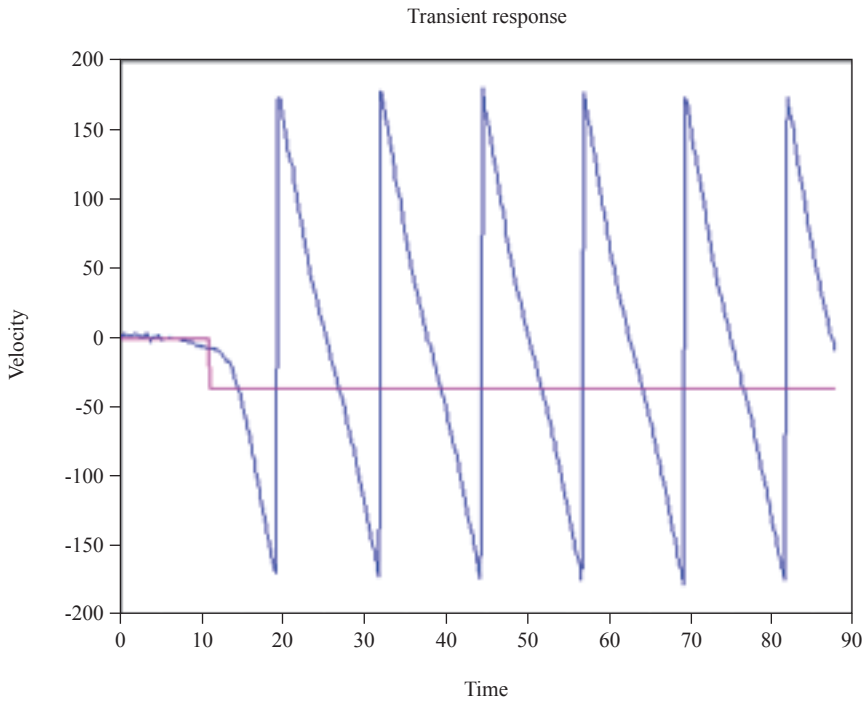


Fig. 6. Evolutionary Circle test.



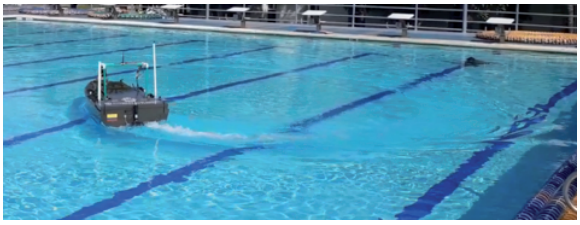
Output) height step was performed at the actuator input.

As can be seen the boat reaches an average speed of 3 knots and that the response describes a first order plus dead time behavior.

Similarly, Fig. 6 presents the results of a performance of the tests in phase 2 of the experiment described in section 4.

Note that Fig. 6 shows the instant in which the propellant nozzle performs a step step of -74%CO which generates the USV to start turning and perform 5 complete turns. Fig. 7 presents an image of the test in question. The circular wake that the boat describes in the water can be seen.

Fig. 7. USV in Evolutionary Circle test.



System models

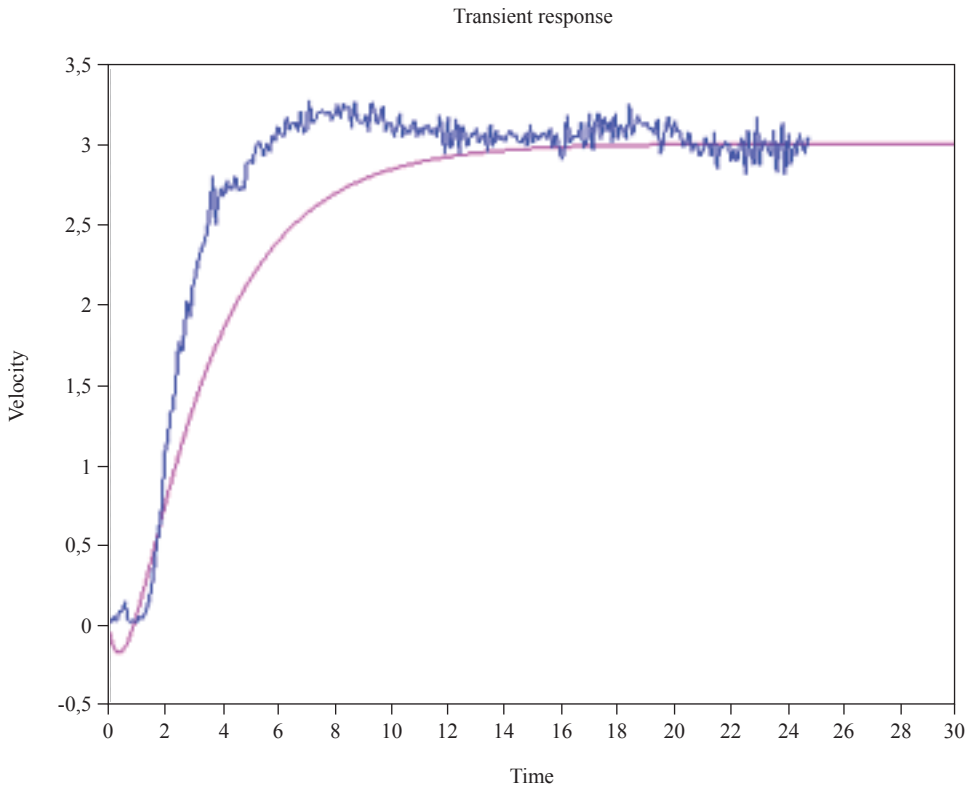
Taking into account the tests and the results obtained in them, for the velocity model it was possible to find the first order plus dead time model that fits the response described by the USV, a fit that is explained by *(Smith, et al., 1997)*. This model is presented in equation 7.

$$G(S) = \frac{0.335\, e^{-1.2S}}{3s + 1} \tag{7}$$

To validate the relevance of the model, SciLab simulation software was used to see both the actual USV response and the model response to the same input. Fig. 8 presents these results.

The dead time simulation is observed as a negative curve. But this is because the dead time was simulated using the first order Padé approximation. *(Alfaro, 2002)*. However, it should be noted that the approximation allows to see a response very close to the reality of the system. This is verified by calculating the correlation coefficient between the real response and the model response, which for this case yielded a correlation of 95.2%.

Fig. 8. Velocity Response Vs Model.



Likewise, the second order Nomoto model was obtained and validated, which is described in equation 8.

$$G(S) = \frac{0.004}{864S + 0.4364} \qquad (8)$$
$$0.04719S + 1.614S + 1$$

Controller tuning

Tuning of the speed controller yielded the following results:

$$k_c = 6.13 \quad \tau_i = 3.51s \quad \tau_d = 0.394s$$

With this controller configuration, simulation tests were performed. Fig. 9 shows the response of the system against an input at the reference of 5 knots.

On the other hand, the course controller tuning yielded the following results:

$$k_c = 6.13 \quad \tau_i = 3.51s$$

This resulted in a transient response curve as shown in Fig. 10.

Conclusions

The navigation tests yielded results that allowed to adjust the dynamic models for both speed and heading, showing correlations between the test signals and the simulations of up to 95.2%.

Once the models were adjusted, it was possible to calculate the parameters of the speed controllers. The parameters for the speed controller were K_c = 6.13, τ_i = 3.51s, τ_d = 0.394s. and for the heading controller the calculation was K_c = 6.13 y τ_i = 3.51s.

With the tuning of the controllers it was possible to run simulations that shed light on their behavior. And that will be the reference to determine if the results obtained from the navigation tests with the controllers are valid or not.

Fig. 9. Velocity Response Vs Model.

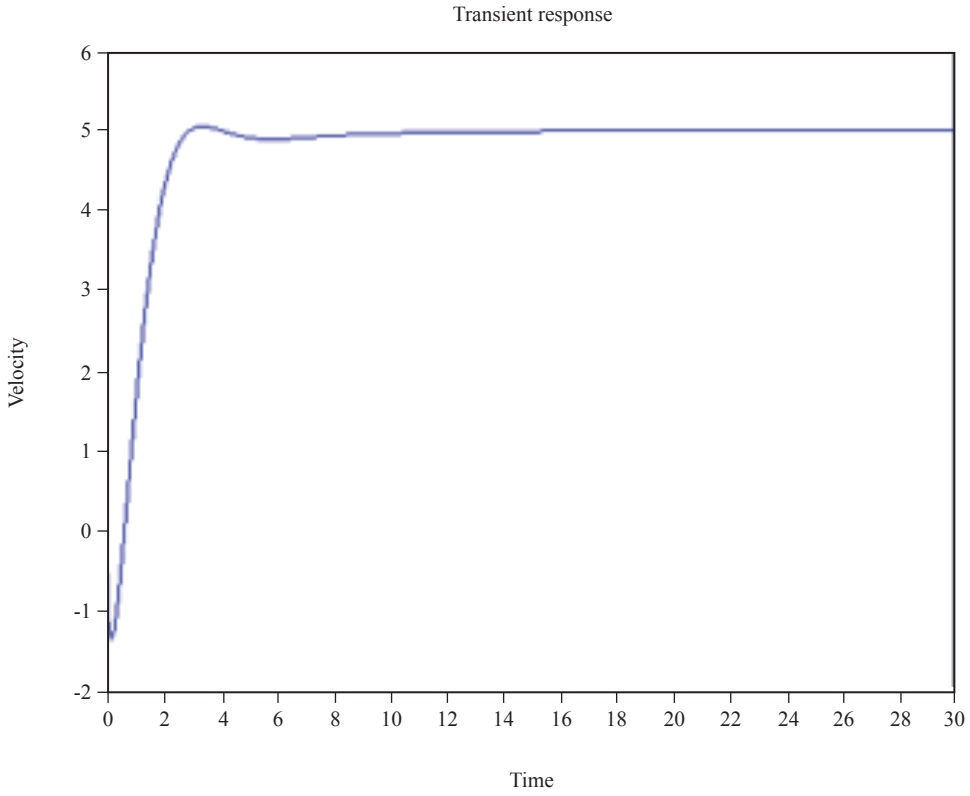
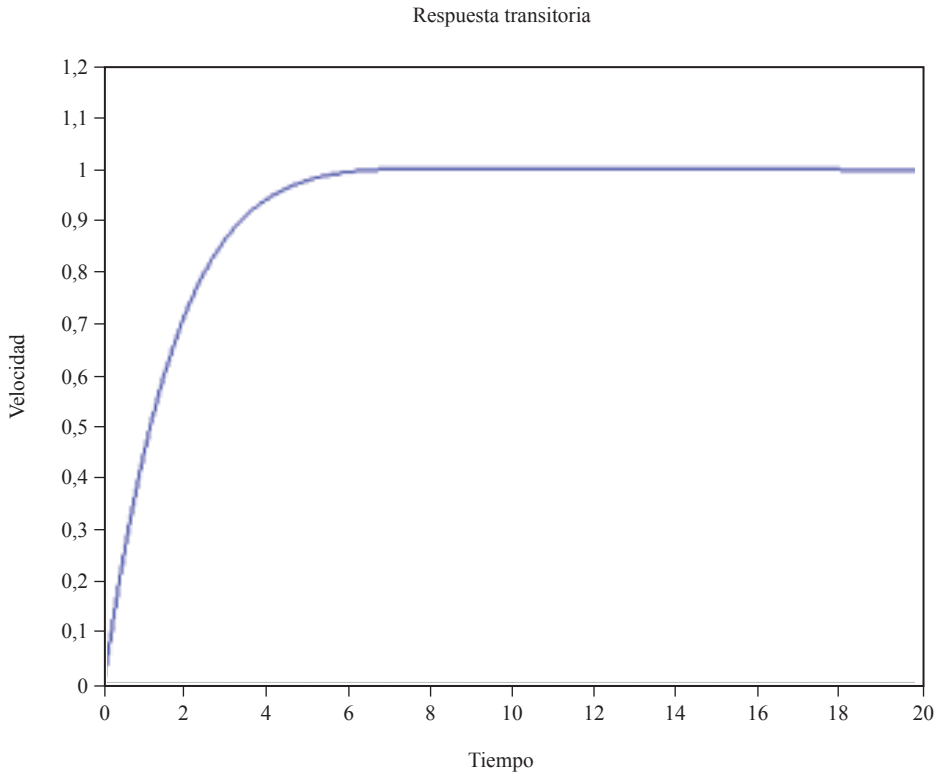


Fig. 10. Heading control response.



Future Work

The navigation tests to validate the behavior of the controllers have yet to be carried out. These tests should in principle be carried out independently.

This means that for the speed control test the heading controller must be off and for the heading control test the speed controller must be off.

Subsequently, a test should be performed with both controllers operating, but making changes in the references of both controllers at different time instants.

This should make it possible to evaluate to what extent these two control loops can work simultaneously without interfering with each other.

Acknowledgement

The writing of this article was possible thanks to the joint participation of the Naval Cadet School "Almirante Padilla", COTECMAR and the Naval NCO School "ARC Barranquilla" in the execution of projects No. 64723 and 75836, the latter being the one that has given rise to the writing of this article.

All of the above has been possible thanks to the financing of the aforementioned projects by the Colombian National Navy through MINCIENCIAS.

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Pedagogical Strategy for the Generation of Capabilities in the Development of Unmanned Surface Vehicles - USVs.

Estrategia pedagógica para la Generación de Capacidades en el Desarrollo de Vehículos de Superficie No Tripulados – USVs.

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Abstract

This paper presents the preliminary results of the implementation of a pedagogical-research strategy, oriented to the generation of capabilities in the development of Unmanned Surface Vehicles - USVs at the Naval Cadet School "Almirante Padilla", with the support of the Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval, Marítima y Fluvial - COTECMAR. The strategy implemented is based on the linking of undergraduate students to research projects oriented by the Research Groups, under the guidance of the professor, who acts as a researcher and at the same time fosters the environment for cooperative and interdisciplinary work among the participating students. Three significant experiences are presented that show clear results in the development of USVs.

Key words: Pedagogical-investigative strategy, Unmanned Surface Vehicle, Project Ship, Project Sábalo, Hydrocontest.

Resumen

El presente trabajo presenta los resultados preliminares de la implementación de una estrategia pedagógica-investigativa, orientada a la generación de capacidades en el desarrollo de Vehículos de Superficie No Tripulados - USVs en la Escuela Naval de Cadetes “Almirante Padilla”, con el apoyo de la Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval, Marítima y Fluvial – COTECMAR. La estrategia implementada se fundamenta en la vinculación de estudiantes de pregrados a los proyectos de investigación orientados por los Grupos de Investigación, bajo la orientación del profesor, quien funge como investigador y a la vez propicia el ambiente para el trabajo cooperativo e interdisciplinario entre los estudiantes participantes. Se presentan tres experiencias significativas que demuestran claros resultados en el desarrollo de USVs.

Palabras claves: Estrategia pedagógica-investigativa, vehículos de superficie no tripulados, Proyecto Buque, Proyecto Sábalo, Hydrocontest.

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Introduction

Unmanned Surface Vehicles (USVs) are devices that travel on the surface of the water without submerging and can be operated from an office or programmed routes (Drone Spain, n.d., para. 5). They are widely used by different countries around the world for the development of maritime missions, mainly mine warfare and countermeasures (MCM), anti-submarine warfare (ASW), intelligence, surveillance and reconnaissance (ISR), maritime and port security, surface warfare (ASUW), support to special forces groups and electronic warfare (EW). At a national level and observing this wide spectrum of applications, we find that the naval industry does not present significant developments of USVs, being this a great opportunity for development due to the maritime potential it has.

In this way, the Colombian Navy, recognizing its fundamental role, assumes the leading role in promoting technological development in the country and enhancing the technological R&D&I capabilities of the naval sector. In this sense, the Navy intends to "migrate to operational scenarios of greater efficiency, from the introduction (acquisition or generation) and implementation of new technologies, promoting research within the institution and effectively articulating with its main technological development center, the Corporation of Science and Technology for the Development of the Naval, Maritime and Riverine Industry (COTECMAR), the research centers of the General Maritime Directorate (DIMAR), the other research centers, the academy and the industry" (National Navy, 2015, p. 42).

This fact has boosted the growth of the Colombian naval industry, mainly concentrated in COTECMAR, an entity belonging to the Colombian Navy - ARC, which has been working in this field of scientific and technological research, supporting the development of the maritime industry. Currently, COTECMAR dedicates its efforts to the advanced design, construction and maintenance of naval platforms *(COCTEMAR, 2021)*. However, a first step for the start, sustainability and development of the USV production line has to do with strengthening the research capabilities of the sector's human resources, many of whom are Naval Officers trained at the "Almirante Padilla" Naval Cadet School (ENAP).

As a consequence, ENAP, as the alma mater of the National Navy Officers, carries out research projects in which students are involved through their degree projects, based on a pedagogical-research strategy, whose purpose is to deepen the knowledge delivered to its students, promoting the development of R+D+i capabilities and proposing methods that offer effective and versatile solutions to environmental problems, hand in hand with strategic allies such as COTECMAR, DIMAR, the Department of Weapons (DARET), universities and private industry; in such a way that this, as a whole, ends up being effectively articulated with ENAP's substantive functions. In this sense, this article presents the results of a significant experience, based on a pedagogical-research strategy implemented, called "Project Vessel" and the way it has promoted the generation of capabilities in the development of Unmanned Surface Vehicles at ENAP.

ENAP Pedagogical Model

"ENAP is an institution that depends organizationally on the National Navy, focuses its function in a coherent and relevant way for the comprehensive training of Officers and Cadets of the National Navy, Merchant Navy and professionals in the maritime sector (...)" *(ENAP, 2015)*. It has, among others, the faculties of Maritime Administration, Naval and Nautical Sciences, Physical Oceanography and the Faculty of Naval Engineering (FACIN). In turn, the Faculty of Naval Engineering develops the academic programs of Electronic Engineering and Naval Engineering, mission programs, created to meet the specific needs of the National Navy.

"The need for training at the professional level requires educational institutions to include innovative strategies in their academic offer

with which competent professionals, capable of responding to market requirements, are profiled in each cohort" *(M. F. Serrano Guzmán, N. C. Solarte Vanegas, 2015)*. This implies the adoption of a Pedagogical Model of learning that supports the teaching methodologies in which each academic program is offered. In the particular case of ENAP, the Institutional Pedagogical Model is based on a particular relationship between the aspects related to military and academic training, the directive authorities, the teacher-mediator, the military instruction and the student, within a characteristic context in accordance with the hierarchical institutional nature. "This pedagogical model focuses on the constructivist and cognitive-behavioral theoretical reference, which, are applicable to all programs as the main guide, without leaving aside the other methods that are complementary due to the humanistic and social components of the subjects" *(ENAP, 2016)*.

Constructivist models conceive the teacher as a mediator between the experience of the environment and the processes of appropriation and construction of knowledge in students. Their role is to generate conditions, promoting the emergence of questions and interactions for meaningful, pertinent and structured learning. This requires qualified teachers, reflected in competence and willingness to provide support, transferring the domain of knowledge to the student in which autonomous learning and personalized accompaniment for academic activities are privileged.

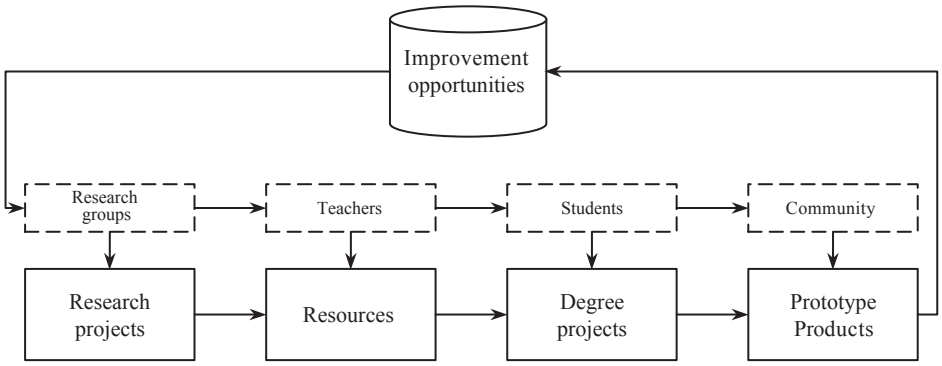
Formative Research at the School of Naval Engineering - FACIN:

The current role of engineering in the country requires the active participation of both public and private organizations that promote the generation of opportunities for the development of R&D&I activities from a scientific-technical perspective. Thus, ENAP has been strengthening its research and innovation culture, knowledge transfer, entrepreneurship and creativity. There is a whole research ecosystem formed by the Research Dean's Office (DIDEN), the Center for Innovation, Development and Research for Maritime Activities - CIDIAM, the different Academic Dean's Offices, the strategic allies (COTECMAR, DIMAR, DARET), among others. ENAP has created a model to strengthen the formative research process, in which three subjects are integrated in its first training cycle professional (Formative Research I, Formative Research II and Formative Research III) and two subjects (Project Management and Degree Work) in the Professional Complementation courses, thus promoting the formation of an investigative, creative and innovative spirit in the students.

On the other hand, the School of Naval Engineering, through the document "Guidelines for Formative Research", defines the criteria, strategies and activities of the program that promote the formation of a research, creative and innovative spirit in the students. This, in accordance with the policy of the National Navy, in which the degree project of the Naval Officers must be oriented to solve real problems of the Institution, has made the degree project one of the mechanisms that most contributes to the development of the substantive functions of the academic programs.

In response to the above and in compliance with the mission requirements of the Colombian Navy (Naval Officer Training), the Ministry of National Education "MEN" (Qualified Registration and High Quality Accreditation of the Program), the ENAP (Institutional Accreditation), the naval industry and society in general, the DFIN strategically aims to develop research projects, framed in the research lines of its Research Group in Naval Control, Communications and Design (GICCDN). This pedagogical-research strategy incorporates elements of the Project Based Learning (PBL) methodology, a strategy where the student is involved in the design, problem solving, decision making, or research activities; giving him/her the opportunity to work autonomously for a long period of time; and culminates in products or realistic presentations close to the professional world *(Fernandez, 2006)*. In this way, students develop their degree projects from the solution to problems that arise from research projects.

Fig. 1. Methodological process of pedagogical-research strategy FACIN.



Source: Own elaboration, based on FACIN reference.

The Naval Control, Communications and Design Research Group (GICCDN) is responsible for promoting research in the Faculty. Its research lines in the naval area (Research Line in Naval Architecture - Sub line "Design of ships, naval artifacts and unmanned vehicles") and in the electronic area (Research Line in Robotics and digitalization: 4.0 - "Platform control system" sub-line and Sensors, communications and simulation research line - "Communications development" sub-line), are integrated to generate projects oriented to the development of USVs. In this way, interdisciplinary and multidisciplinary work teams are formed, with the participation of Naval Engineering and Electronic Engineering students, teachers and researchers. The methodological process is shown in Fig. 1. In this way, formative research is enriched to the extent that it promotes observation and critical analysis to find solutions to environmental problems, with different approaches and tools. Thus, while formative research develops students' logical and creative thinking, project work puts thinking into action through practical applications such as prototypes, processes or systems and prepares students to understand how to conceive, design, implement and operate complex engineering systems based on participation in work teams (...), as Crawley (2001) points out.

In this pedagogical-research strategy, from the constructivist theories, the teacher-researcher in his role of mediator proposes research or technological development projects in which students are involved. In this way, there is an interaction between the teacher and the students; the teacher in his role of supervisor, advisor, researcher and the students as executors of the project. The students' degree projects are then the appropriate academic space in which teachers, students, managers, researchers and entrepreneurs interact to propose solutions to real problems of the environment.

Research Pedagogical Strategy

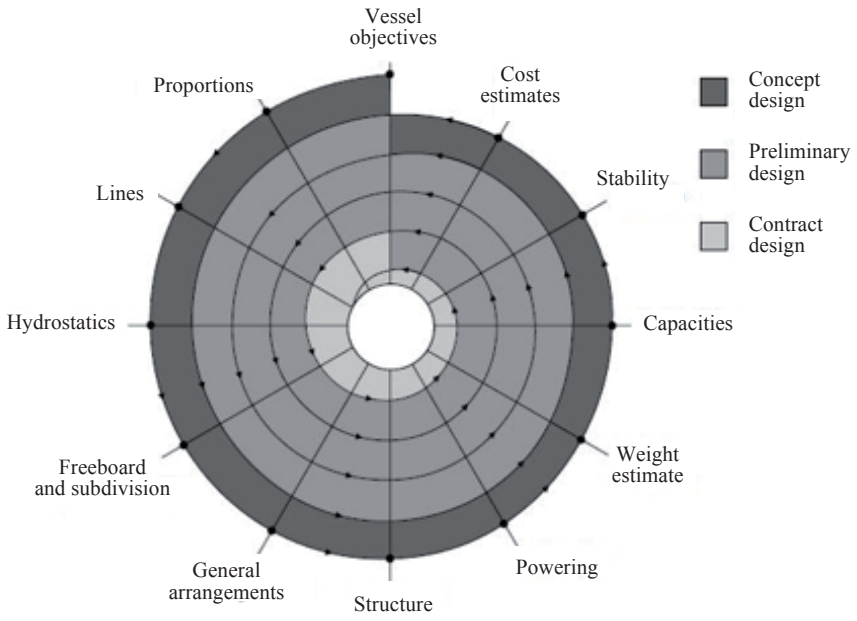
The following are three significant experiences developed under the pedagogical-research strategy presented.

Ship Project

The "Ship Project" was launched in 2016 by CF. Roberto Carlos Ángel as a research strategy, based on a research project funded by the National Navy of Colombia (ARC) focused on to the conceptual design of an instruction and training ship for the Naval Cadet School "Almirante Padilla". As an academic-research strategy, students develop their degree projects and strengthen their engineering competencies and strengthen the professional and occupational profile of the career.

The implementation of the strategy involves the use of methodologies specific to the discipline; in the case of naval engineers, it is based on naval design. Students learn knowledge about computational tools, handling of specialized software (Maxurf, CFD, Autocad, Rhino, Hydromax), apply the

Fig. 2. Design spiral.



Source: (González, 2011).

knowledge of the subjects of the study plan and generate research habits through the search for bibliographic information. For its part, the "Ship Project" is based on naval design, following the design spiral methodology ("Fig. 2"). "This is a cyclical and iterative methodology, where they establish and develop the concepts proposed in each phase of the project with the consideration that these concepts have a direct relationship with each other" *(Bello, 2016)*. The design spiral is applied in all phases of the project. It starts with very general and unclear concepts of the conceptual design, which are determined and related in each of the phases of the project until reaching its center or detail design phase. That is why the project of a ship is characterized by being cyclical and also seeks as time progresses to develop a higher level of detail in each of the aspects it addresses, so it has some phases that are set as objectives that will lead to the realization of the design and construction of the vessel.

The ship project follows a methodological and research process that is evidenced through the development of design booklets, as shown in Table 1. As a result, the hull design of prototype ships at different scales and specifications is obtained, which are the basis for the development of USVs and/or prototypes on which Colombian naval industry developments are based. Such is the case of the amphibious landing ship - BDA, which, as described in the Report of Science, Technology and Innovation Activities of COTECMAR, began as the product of a meritorious degree work of two ARC officers, entitled "Preliminary design of a landing ship type LCU for the ARC". This project is also a successful example of the University-Company-State relationship *(COTECMAR, 2014)*.

On the other hand, the Electronic Engineering students are the complement of the interdisciplinary approach. Following the methodology of technological development, with emphasis on the design of electronic systems ("Figure 3"), they develop the hardware essential for the functioning and operation of the USV. In this way, they design the navigation control systems, speed control, electrical power, propulsion, telemetry, sensors and wireless communications, essential for the command and remote control of the vehicle. In the same way, these students strengthen their knowledge in computational tools and handling

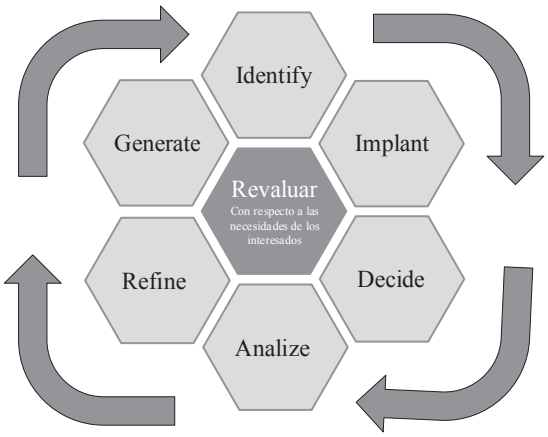
Table 1. Methodological and research process "Project Vessel".

Phases	Measure
Booklet 1	Mission profile study, shipowner requirements, definition of main dimensions, etc.
Booklet 2	Shape design, hydrostatic characteristics, presentation of the general arrangement plan, shape plan.
Booklet 3	Estimation of forward resistance, definition of power to be installed, definition of propulsion line.
Booklet 4	Estimation of weights, definition of theoretical light displacement, definition of centers of gravity for light condition, stability analysis and application of stability criteria.
Booklet 5	Calculation of scantling by means of rules and design of the master frame, master frame drawing.
Booklet 6	Design and definition of the power generation system.
Booklet 7	General cost estimate.

Source: FACIN.

of specialized software (Matlab, Labview, Proteus), applying the knowledge seen in the subjects of the study plan.

Fig. 3. System design process.



Source: Own elaboration based on (Burkhardt, 1996).

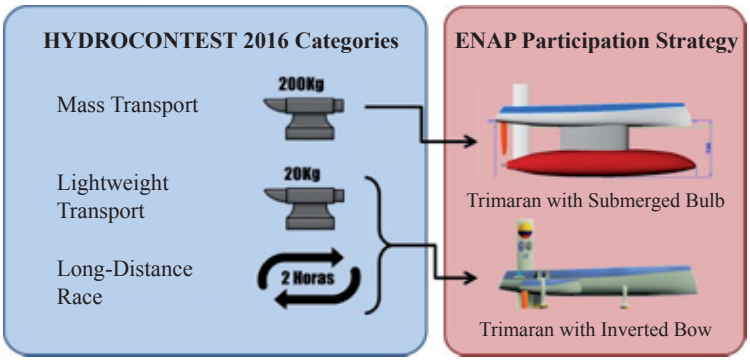
Hydrocontest Project

The "Hydrocontest Project" arises as a response to the challenge posed by the Hydrocontest International Competition, a competition organized annually by the Hydros Foundation. This Foundation is an accredited non-profit public interest foundation, whose objective is to promote technological innovation in response to the energy and environmental challenges facing the marine and maritime industry and to raise awareness of these issues among professionals, students, opinion leaders and the general public *(Hydros Foundation, 2020)*. The competition has as its philosophy energy efficiency in naval vessels, offering three competition modalities (speed, distance and load capacity), in which students carry out their technological developments, research and innovations aimed at the design of boats that make more efficient use of energy. The competition has been held since 2014 and provides participants with the same electric propulsion motor and the same battery, as a source of energy, to meet the different challenges.

The "Hydrocontest Project" is conceived as a technological development, being the continuity at a more advanced level of the "Project Ship", using the same philosophy and methodology of naval and electronic design. In this case, it emphasizes the development of prototypes of highly energy efficient naval vessels, it has a scope ranging from the naval design of the USVs to the development of hardware and software, essential for the control and operation of the same from a shore station *(Puello and Gutierrez, 2016)*. In this project, as an academic-research strategy, students develop their degree projects always with the accompaniment of research professors and advisors. This is aimed at multiple purposes, such as the development of energy-efficient USVs, strengthening teamwork, interdisciplinarity, institutional visibility, exchange of experiences, academic mobility and international interaction of students.

The development of USVs for the Hydrocontest competition started in 2016, with the design of two Trimaran type USVs (Trimaran with submerged bulb and Trimaran with inverted bow), with the hull shapes and characteristics for the Hydrocontest competition, as shown in Figs. 4 and 5. The project involved the design of the shapes, hydrostatic characteristics, presentation

Fig. 4. Hydrocontest 2016 participation strategy.



Source: (Gutiérrez, B. J. P. and Puello, O. M. 2016).

Fig. 5. Trimaran Hydrocontest competition.

Source: (Gutiérrez, B. J. P. and Puello, O. M. 2016).

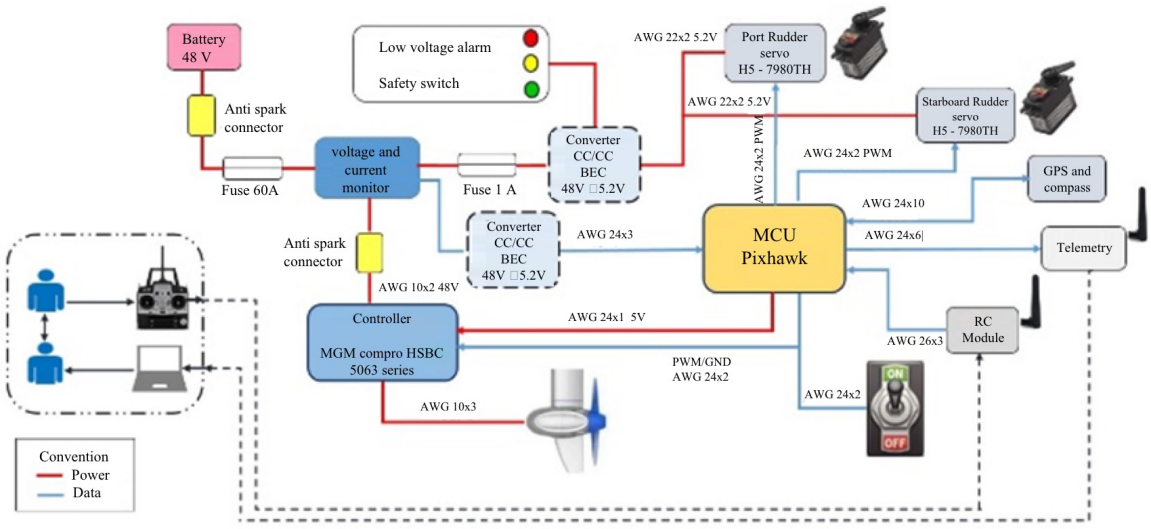
of the general arrangement plan and shape plan, estimation of the resistance to advance according to the power of the propulsion motor. Stability calculations were performed for a specific load (20 kg) in the light transport category and autonomy test, estimation of its behavior with respect to the estimation of weights and definition of centers of gravity were made *(Bello, 2016)*.

The design and modeling was done with Maxsurf, Rhinoceros and CFD software. In the electronic part, in charge of Electronic Engineering students from ENAP and Mechatronics Engineering students from the National University of Colombia, the steering and propulsion control was designed, consisting of a radio control system and sensors such as accelerometer, magnetometer, gyroscope, barometer and GPS. Likewise, telemetry systems were implemented to monitor battery parameters, a Binary Data Logger to store navigation data and a Human Machine Interface (HMI), where telemetry and navigation control data are displayed. See Fig. 6.

In subsequent developments of USVs, Catamaran type vehicles were designed with hydrofoils implementation, oriented to energy efficiency *(Roa Almanza and Romero Lizcano, 2017; Riomaña and Polanía, 2018)*. These naval designs were carried out following the design spiral. Likewise, the corresponding calculations were performed through computational tools, obtaining an efficient and low-cost naval prototype that met the requirements of the competition. The design of these prototypes aimed at optimizing the shapes, use of composite materials, studies of resistance to the advance and implementation of appendages, thus improving the performance of the vessel. See Fig. 7.

In the electronic part, improvements were introduced, such as the development of an artificial vision system with remote video transmission in real time, as an aid to the pilot's navigation; microcontrollers were integrated for the two-plane control of a video camera installed in the USV; development of the graphic interface for monitoring and visualization of telemetry signals of the battery status; in the same way, a video transmitter/receiver was implemented for the visualization of the navigation environment, a radio data link (XBEE) for the wireless transmission of signals from an inertial sensor (IMU), which measures the

Fig. 6. General control diagram.



Source: Own elaboration taking as reference (Galvis & Pineda, 2016).

orientation of the pilot's head (lateral and vertical movement); this in turn serves as a control signal for the camera. *(Osorio and Nova, 2018).*

Fig. 7. Hydrocontest Catamaran.

Source: (Riomaña and Polanía, 2018).

The implementation of this strategy has brought together a work team made up of professors and students of Electronic and Naval Engineering from ENAP, students of Mechatronics Engineering from the National University of Colombia and advisors from COTECMAR.

Sábalo Project

This academic-research strategy has as its starting point the Proposal for Technology Transfer of the Autonomous Coastal Aquatic Search System "SÄBALO", 2013-2014, carried out by the Innova Group Organization of Spain, as a product of the offset between the National Navy and the company Otto Melara, for the development of the modernization project of the National Navy's Missile Frigates and the implementation of new technologies in the cannons on board. Basically, it involves the construction, technology transfer and delivery of 02 unmanned surface boats (see Fig. 8), equipped with various equipment (Microprocessor, navigation and surveillance cameras, Global Positioning System (GPS), Automatic Identification System (AIS), thermographic camera, among others) that allow it to develop operations in maritime and river environments *(In-Nova, 2015).*

Fig. 8. USV Sábalo.

Source: Own elaboration.

The scopes defined for the Offset agreement became the starting point for the challenges faced by the National Navy to generate new capabilities to replace the existing software (owned by third parties) and to enable the specification and development of proprietary and national hardware components, allowing the reduction of foreign technological dependence on these technologies.

This project is considered as the methodological chaining and the technical-practical application of the strategies that began with the "Ship Project", which gathers all the experience accumulated in the "Hydrocontest Project"; likewise, the availability of technologies and sensors of the SABALO project, allow acquiring an important experience as a mobile laboratory for different generations of students of the Naval School, who, guided by the teaching staff, propose new developments to be executed with resources acquired through MINCIENCIAS-ARC calls for proposals. In this way, a technological development is obtained that has been evolving and improving the performance of the USV. Engineering students from ENAP, research professors from ENAP's GICCDN group in association with strategic allies such as the Research Group of the Naval Design and Engineering Program (PRODIN) of COTECMAR and the Research Group on Naval Engineering Technologies of the Naval School of Non-Commissioned Officers "ARC Barranquilla" (GITIN) have participated in this research project, which was born from the execution of research projects.

One of the projects formulated and executed to improve the technological development of the USV was entitled "Development of the Navigation Control System of the Unmanned Surface Vehicle "Sábalo" for its implementation in Maritime and River Patrol Operations", financed by MINCIENCIAS-ARC. Researchers from GICCDN and GITIN participated in this research proposal, oriented to the design and implementation of an autonomous navigation control system of their own, adjusted to the needs of the Colombian environment and the Colombian Navy. This project allowed the linkage of students through degree projects, in which the telemetry system for the monitoring of geographic position, roll, pitch, and magnetic orientation of the unmanned surface vehicle "Sábalo", IMU systems, GPS, in addition to the replacement of some technologies, achieving better control by the operator regarding the location and exact direction of the vehicle during navigation were developed *(Camacho, 2017)*.

A second degree project implemented the wireless radio frequency control system for Pan-Tilt-Zoom (PTZ) cameras in the UVS, which are used for obstacle avoidance and field of view enlargement during navigation. For this, they used radio transmitters and control codes from a Virtual Instrument (VI) developed in Labview, using the PELCO-D protocol *(Amador and Correa, 2017)*. A third degree project obtained the mathematical velocity model of the USV Sábalo that was subsequently used for the design of the remote navigation control system. For this, it implemented an instrumentation system with an IMU measurement sensor *(Buchheim, 2018)*. Likewise, Vargas and Canticus (2019) developed a photovoltaic-powered radio beacon for implementation in the USV Sábalo as an aid to the geolocation and recovery of the vehicle in situation of loss of the radio data link or battery discharges. The developed system is based on a network of electronic devices capable of processing and communicating by radio frequency its GPS position to be monitored in real time from the command console of the USV Sábalo. The device was integrated in the USV's bow compartment and can be activated automatically when it senses a sudden change in voltage or in the signal emitted by the system; when activated, the position of the USV will be known, a situation that makes salvage and location of the platform possible.

Another degree project related to the "Sábalo Project" was developed by Mejía and Impata (2020), who evaluated the performance of PI - PID controllers for the USV automatic speed control system, achieving a tuning that improved the USV operation in the remote control operation mode.

The development of this project with MINCIENCIAS-ARC made it possible to replace

the navigation control system of the USV Sábalo with another processing core, with more robust components from National Instruments (Compact RIO). Compact RIO is an embedded industrial controller that operates in real time, oriented to industrial control and has reconfigurable I/O modules, FPGA module and an Ethernet expansion chassis, compatible with MyRIO boards and Labview software *(National Instruments, 2020)*. This new system facilitates logic communication between devices, using TTL and UART transmitted signals and conversion between RS-232 to RS-485 signal protocols and vice versa. This USV is capable of performing semi-autonomous remote control assisted navigation.

All actuators and sensors installed on the USV shad are listed in Tables 2 and 3.

Table 2. Actuators installed at USV Sábalo.

Team	Manufacturer	Model
Engine	TP Power	TP100
Engine Water Filter	TP Power	CJ100
Controller	ALIEN POWER	APS9-60
Waterjet	MHZ	Jet 80
Coupling Waterjet - Motor	R+W	EKH 010/B 12H7- 12H7
Servo	HITEC	HS-7954SH
Servo Bellows	HALLTECH	F 1502 NBR
Linear Actuator	Unknown	Unknown
Rudder blade	INNOVA Foundation	Unknown

Table 3. Sensors installed at USV Sábalo.

Team	Manufacturer	Model
Transducer Depth (Dt800)	Airmar Technology	44-084-1-01
Transducer Speed (CS4500)	Airmar Technology	44-013-1-83
IMU	CH Robotics	UM7-LT
GPS	V.KEL Communications Equipment	VK2828U7G5LF
T-View camera *	Control	T-VIEW-Z
Flir camera *	FLIR	432-0003-12-00
Chambers of Navigation	Hangzhou ISmart Video Tech	IS-VS1803

Currently, the "Sábalo Project" continues its course of evolution, scaling its level of technological development thanks to the financing approved by MINCIENCIAS-ARC, for the joint execution between COTECMAR and ENAP, of the project identified with code No. 75836 and entitled "Development of a technology demonstrator (TRL5) for the Unmanned Surface Vehicle for the Strategic Surface Platform (PES), focused on the communications system and its integration with the navigation control developed by ENAP for its future implementation in the USV of the PES".

This project is aimed at developing the communications system, the control station and the communications interface of the USV Sábalo with the naval tactical network of the ARC. For this purpose, we are working on the adaptation of a communications system that allows the transfer of control and telemetry data, as well as the transmission of video between the control station and the unmanned platform; likewise, a portable control station is being developed to allow the operation of the system from a remote location, incorporating new functions to the navigation algorithms.

The research groups of COTECMAR (PRODIN) and ENAP (GICCDN) participate in this project, as well as students of Electronic Engineering of ENAP.

Currently there is a related degree project, oriented to the tuning and performance evaluation of PI - PID controllers for the course control system of the USV "Sábalo".

Thus, the participation of students in this research project, guided by the faculty and researchers of COTECMAR and ENAP, is relevant to achieve the proposed objectives.

The strategy for obtaining capabilities is focused on the anthropic impact of the naval community within the shad model base that involves the participation of the STATE-UNIVERSITY-BUSINESS, where knowledge and decision making are strengthened under engineering criteria applied to design. In accordance with the above, the dialogue presented in the first instance between teachers/researchers

and students is framed in developing competencies aimed at enabling students to learn on their own, be able to search for information, exercise critical thinking, pose and solve problems, work collaboratively, participate in networks and know how to communicate assertively *(Lipman, 2006)*.

Taking into account the above and in an effort to contribute to the training of future research engineers to build learning communities, research development and capabilities for the solution of real problems of the industry and society in general, the School of Naval Engineering continues the strategy of involving students in research projects.

In this way, the participation of both the student community and the technological and scientific communities and the industry in general with whom we work is promoted, so that students, teachers and communities learn to respond creatively and collectively to their felt problems. *(C. A. Torres Parra and J. Arias Hernández, 2015)*.

Research Pedagogical Strategy

In order to contribute to the training of future researchers in the area of naval engineering and to strengthen the generation of new knowledge, this paper shows the main achievements of the strategy implemented for the development of USVs.

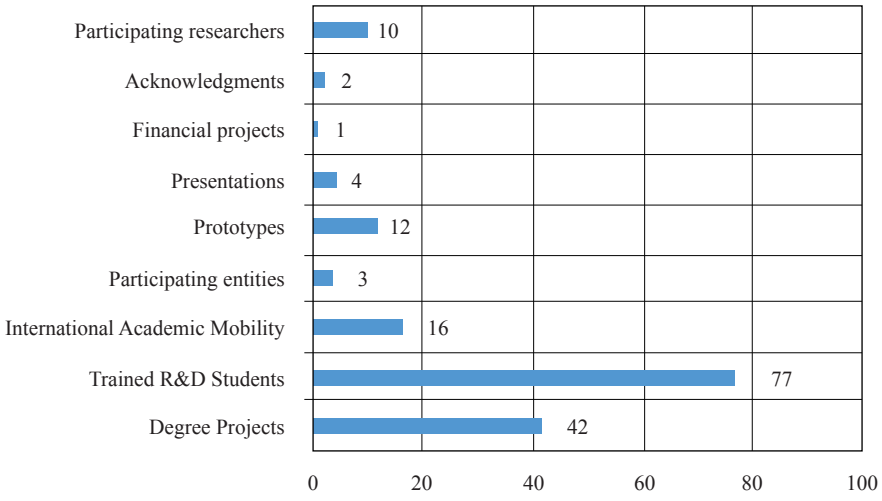
The research pedagogical strategy "Proyecto Buque" has been very prolific, achieving important results, as shown in Fig. 9.

As can be seen, the development of 42 degree projects, 77 students trained and experienced in R&D processes, the conceptual design of 25 vessels, the construction of 12 USV hull prototypes, 5 of which participated in international competitions, and the presentation of papers in national academic events are highlighted, pointing to the indicator of academic mobility of students and teachers.

It is worth mentioning that this project obtained funding from the ARC, involving 10 faculty members and achieving national recognition.

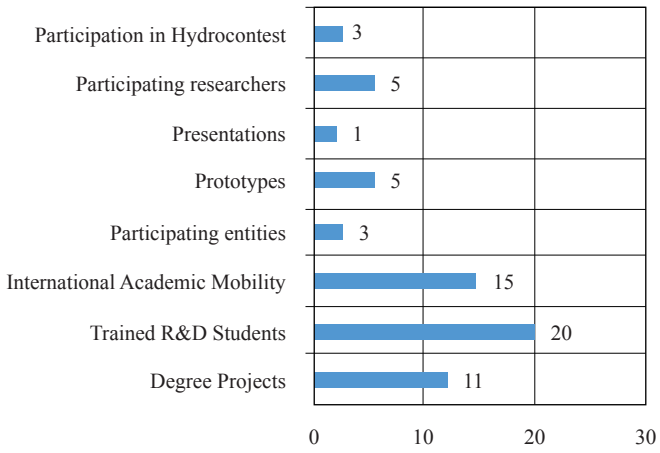
The pedagogical research strategy "Hydrocontest Project" made possible the visibility and international testing of the USVs developed by the group of participating students and teachers. The challenge of participating in a European competition (Lausanne - Switzerland, Saint-Trophez - France) with engineering students from all over the world, motivated the generation of better capacities for the development of USVs, which were evidenced in the evolution of the performance of these vehicles year after year. As shown in Fig. 10, we can highlight the development of 11 undergraduate projects, 20 students trained and experienced in R&D processes, as well as

Fig. 9. "Ship Project" products.



Source: Own elaboration.

Fig. 10. "Hydrocontest Project". Products.



Source: Own elaboration.

the construction of 5 USV hull prototypes (one Trimaran and two Catamaran for speed tests, and two monohulls for endurance and energy efficiency tests), attendance to 3 versions of the competition, 15 participating students, and a presentation at an international scientific event.

At the institutional level, it contributed to the indicators of research, social projection, international visibility, academic mobility of students and teachers. Continuous participation in this competition has made possible the teamwork and interdisciplinary work between teachers and students of Electronic Engineering and Naval Engineering of ENAP, students of Mechatronics Engineering of the National University of Colombia, with the advice and scientific and technological support of COTECMAR.

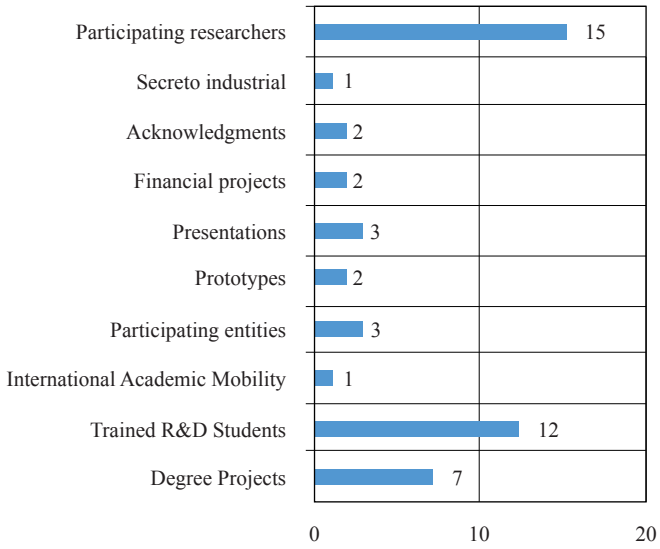
Therefore, the "Project Ship" goes beyond participating in an international competition such as the Hydrocontest contest, but on the contrary, it aims to innovate and propose methods that offer effective and versatile solutions to the problem of cargo transportation, using existing electronic control systems, and innovating in the design of vessels and the use of composite materials for their construction. These solutions may be adopted and enhanced with strategic allies, effectively articulating as mentioned above with COTECMAR, DIMAR, universities and private industry; in such a way that this is just one more step in which the National Navy enhances research in the areas of knowledge allowing to contribute with actions aimed at national maritime development. *(Puello and Gutierrez, 2016).*

The "Sábalo Project", as a pedagogical-research strategy, represents the ideal of integration of the three substantive functions of research, teaching and social projection. As shown in Figure 11, the "Sábalo Project" obtained financing for the execution of two research projects from MINCIENCIAS-ARC, three participating institutions (ENAP, COTECMAR and the NCO School "ARC Barranquilla"), three Research Groups (GICCDN, GITIN and PRODIN), 12 students trained in R&D who developed 7 degree projects. Fifteen researchers have participated and so far have generated two publications, two national and one international paper, an industrial secret and the development of two prototypes.

The level of development achieved in the USV Sábalo has awakened the interest of educational entities and the National Navy itself to generate an advance in the technological independence of the institution, especially in this type of prototypes that are necessary in the complexity of the area of maritime and fluvial operations.

These experiences have strengthened an ecosystem and culture of research and innovation, knowledge transfer and creativity in which students have

Fig. 11. "Project Sábalo". Products



Source: Own elaboration.

strengthened their research skills, appropriated tools and approaches from which problems are addressed; working with other disciplines, different entities and actors, reaffirms interdisciplinarity, promotes the strategic alliance university-business-state, achieving a positive interaction and financing of research projects. It also highlights the collaborative and cooperative work of its members. Recent studies show that teaching in small groups is effective and suggest that greater formative feedback from the teacher, more constant participation in small groups, or work that is more adjusted to the needs of the students, are factors that could explain this impact *(SUMMA, 2019)*; it allows both the development of academic and professional competencies, as well as the development of interpersonal and communication skills.

Conclusions

The pedagogical-research strategy of linking within an ecosystem that combines the techniques of the business sector, the exploration and application of knowledge of the University and the social responsibility of developing solutions to the needs of the state, strengthen the training of students, providing the possibility of generating technological development projects, in this case, to the development of USVs that seek to provide solutions to real problems of their environment, taking advantage of the interdisciplinary management of topics that promote creativity, teamwork and innovation, while articulating with teaching, research and social projection, which are fundamental pillars of higher education.

The contribution to technological progress that has been expanded in each of the projects developed on ship hull designs, type of materials used, communications, telemetry, sensorics and autonomous navigation control systems for unmanned vehicles (USV), have allowed the management of knowledge in terms of systems integration, digitization, controllers and modulation of events for the different analyses in the field of Naval and Electronic Engineering, where it has awakened a great interest among students and the National Navy itself, interested in technological independence, especially in this type of vehicles, which are increasingly used in the complexity of maritime and river operations.

The project "Technological development of a technology demonstrator (TRL5) for the Unmanned Surface Vehicle for the Strategic

Surface Platform (PES)" demonstrates the progress and maturity that is intended to be reached in the short term, in the development of this type of technologies, which has promoted teamwork and interdisciplinary work, the establishment of strategic alliances with common interests, between University-Company-State, the training of personnel in R&D and the appropriation of scientific, technological and industrial capabilities, of strategic interest for the country and the institution, which will have a positive impact on the Colombian naval industry.

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Numerical study for the estimation of the hydrodynamic coefficients of current drag in port assistance maneuvers (dock) for the Colombian Navy frigates by means of CFD

Estudio numérico para la estimación de los coeficientes hidrodinámicos de arrastre de corriente en maniobras de asistencia en puerto (muelle), para fragatas de la Armada Colombiana mediante CFD

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Abstract

Computational Fluid dynamics (CFD) has become nowadays an important tool in the process of hydrodynamic design of modern ships. CFD is used to model any phenomena related to fluid flow in a control volume like a ship or any offshore structure in the sea. In the present study, the Current force drag coefficients for a Colombian Navy Frigate in deep and shallow water are estimated through application of CFD, which are required to estimate the bollard pull for assisting maneuvers at port. The study shows the process of simulating the ship current drag coefficients using the CFD simulations method which is conducted using STAR-CCM+ software package. The Almirante Padilla class Frigate ship CFD scale model is researched. The results show the ship current drag coefficient calculated considering a current speed of 1 knot with a 90° drift angle for the full-scale ship. The model configuration of the present simulation is based on the procedure recommended and published in the Lloyds Register OCIMF and the UFC mooring report for the estimation of the current drag coefficient.

Key words: CFD, Current draft coefficient, STAR-CCM+, OCIMF, ITTC, Bollard pull.

Resumen

La dinámica de fluidos computacional (CFD) se ha convertido hoy en día en una herramienta importante en el proceso de diseño hidrodinámico de los buques modernos. El CFD se utiliza para modelar cualquier fenómeno relacionado con el flujo de fluidos en un volumen de control como un buque o cualquier estructura offshore en el mar. En el presente estudio se estiman los coeficientes de arrastre generados por la fuerza inducida por la corriente para una Fragata de la Armada Colombiana en aguas profundas y poco profundas mediante la aplicación de CFD, para estimar la potencia de tiro requerida en las maniobras de asistencia en muelle. El estudio muestra el proceso de simulación de los coeficientes de arrastre de la corriente del buque mediante el método de simulaciones CFD que se realiza mediante el paquete de software STAR-CCM+. Se investiga el modelo a escala de CFD del buque Fragata clase Almirante Padilla. Los resultados muestran el coeficiente de arrastre de la corriente del buque calculado, considerando una velocidad de la corriente de 1 nudo con un ángulo de incidencia de 90° para el buque a escala real. La configuración del modelo de la presente simulación se basa en el procedimiento recomendado y publicado por Lloyds Register OCIMF y en el manual UFC para la estimación del coeficiente de arrastre de corriente.

Palabras claves: CFD, Coeficiente de arrastre de corriente, STAR-CCM+, OCIMF, ITTC, Fuerza de tiro.

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Introduction

The bollard pull capacity corresponds to the available pulling power capacity of a vessel given by its propulsion system. It is the thrust force supplied by the propulsion through a towline to a fixed point located on land when the towline is tensioned and the vessel's ground speed is equal to zero. This value corresponds to one of the most important parameters required to perform berthing/rigging operations and corresponds to the maximum pulling force that a tug will need to ensure safe maneuvering in port. This parameter varies depending on the local weather conditions at the port of arrival or departure, as well as on the hull shape and the respective loading condition of the vessel.

The required drag or draft force is a combination of three main components: the hydrodynamic, aerodynamic and inertial forces that occur during the maneuver. In addition, the hydrodynamic forces can be divided into two main components: a) the forces generated by the waves, and b) the force generated by the current velocity that exists at the location of the vessel's maneuver. Other factors, such as dock construction, under keel clearance and backing thrusters, are also important in estimating the required final draft force.

Simplified formulations are available in the literature to help obtain the magnitudes of these forces. [1]. The most common forms of these equations are described below:

Wind-induced forces

The wind induced forces follow the general form of the drag coefficient defined for fluids. The general form of the equation for the cross-sectional wind force exerted for a vessel is obtained from the guidelines given by the UFC [2] as shown:

$$F_{yw} = 0{,}5\,\rho_a V_w^2 A_y C_{yw} f_{yw}(\theta_w) \tag{1}$$

Where, F_{yw} is the transverse force of the wind, ρ_a is the air density, V_w corresponds to the wind speed, A_y is the longitudinal projected area of the vessel, C_{yw} is the transverse drag coefficient and $f_{yw}(\theta_w)$ is defined as the shape function that takes into account the angle of incidence of the wind.

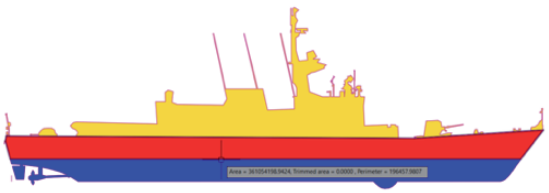
Current induced forces

The current-induced forces also follow the general form of the drag coefficient equation. The CFU document describes it as:

$$F_{yc} = 0{,}5\,\rho_w V_c^2 L_{wL} T C_{yc} \sin(\theta_c) \tag{2}$$

Where, F_{yc} is the transverse force induced by the current, ρ_w is the density of the water, V_c is the velocity of the current, L_{wL} is the length of the water line, T is the draft, C_{yc} is the transverse drag coefficient, and θ_c is the angle of the current direction with respect to the vessel. [2]. The Fig. 1 shows the longitudinal view corresponding to the draft used, and is applied to estimate the projected areas required in the analytical formulation.

Fig. 1. Profile view of the Almirante Padilla Class frigate.



The formulation mentioned in this section considers the effect of shallow water, as well as some predefined constants that can be selected depending on the type of hull being analyzed, in this case specific constants for ships and barges are included.

Wave-induced forces.

Considering a zero towing speed, the wave-induced force can be estimated using the formula found in the DNV guidelines [3] guidelines, as indicated:

$$F_{wd} = \frac{1}{8}\,\rho_w\, g\, R^2 B\, H_s^2 \tag{3}$$

Where, ρ_w is the density of water, g is the acceleration of gravity, R is the reflection coefficient assigned according to the shape of the object, and H_s which

represents the average wave height in the area. The wave induced force increases linearly with velocity and can be described by the following equation:

$$F_{WD}(U) = F_{WD}(0) + U\,B_{11} \tag{4}$$

Where, F_{WD} is the force induced by the waves with a forward speed of 0, and B_{11} is the damping constant of the wave force.

Inertial forces.

This force is the sum of the forces generated by the moving object within a fluid and the inertia forces represented by the surrounding fluid, added mass. [3]. The inertial forces of the floating object in motion can be expressed by the following equation:

$$F_I = -(M + A)\,\ddot{x} \tag{5}$$

The added mass "A" is a function of the added mass coefficient:

$$A = \rho_w C_A V_R \tag{6}$$

Where, C_A is the added mass coefficient, ρ_w is the density of water and V_R is the reference volume of the object.

To determine the required pulling force for a maneuver, all previously defined parameters must be calculated following the appropriate assumptions effective for each case, as well as adding a suitable safety margin to ensure a safe maneuver.

Computational fluid mechanics. CFD

The use of CFD tools to solve the equations describing the behavior of a fluid corresponds to an alternative method to estimate the forces generated by the interaction of a fluid flow and a floating body. The set of equations that define the behavior of fluid flow corresponds to the equations of continuity, mass, conservation of energy and momentum, also known as Navier Stokes equations. [4]. These equations can take into account effects such as instability, convection, pressure and viscous effects of a fluid, as well as volumetric forces affecting the phenomenon. The general form of the Navier Stokes equation [5] equation can be expressed in a simplified form as shown below:

$$\begin{cases} \dfrac{\partial u_i}{\partial t} = 0 \\ \dfrac{\partial u_i}{\partial t} + u_k \dfrac{\partial u_i}{\partial X_k} = -\dfrac{1}{\rho \partial X_i} + \nu \dfrac{\delta^2 u_i}{\partial X_K\, \partial X_K} + fi \end{cases} \tag{7}$$

The solution of this system of equations is possible for certain cases in which some reductions are valid. For other cases it is possible to use numerical methods and obtain an approximate solution.

Currently, with the help of computational capabilities the application of numerical methods such as the RANS (Reynolds Averaged Navier Stokes) equations coupled to turbulence models related to the mean and fluctuating velocities of a flow, which allow to deliver a very approximate solution. This method corresponds to the one most commonly used in modern CFD packages such as STAR-CCM+, FLUENT, etc.

Case Study

In order to meet the current needs of the Colombian Navy and perform adequate and safe docking maneuvers at the Naval Base located in Malaga Bay in the Western Pacific of Colombia, the analysis of the maximum pulling force required for a tugboat to assist the docking and departure maneuver of ships operating in the area is required.

The maritime characteristics of the area make docking and sailing maneuvers a complex task, especially at times when local weather conditions are not favorable.

The meteorological conditions considered for the analysis take into account the effects of tide-induced currents near the pier of a velocity of 1 knot, and wind gusts from the south-west reaching up to 17 knots [6].

For the analysis, the largest vessels operating in the area will be used, corresponding to the Almirante Padilla Class frigates, whose main characteristics are described in Table 1.

Table 1. Main Characteristics of the Frigate.

Frigate "Almirante Padilla" Class	
Displacement (Metric tons)	2100
LOA (m)	95,3
LPP (m)	90,0
Beam (m)	11,3
Prop (m)	3,8
Current speed (knots)	1,0
Submerged projected side area (m^2)	329
Depth (m)	8,0

For the analysis, the largest vessels operating in the area will be used, corresponding to the Almirante Padilla Class frigates, whose main characteristics are described in Table 1.

The above equations (Equation 1 - 6) correspond to simplified models that can be used to estimate the forces present during docking and sailing operations, however, in order to obtain specific data for the Almirante Padilla class frigate, computational numerical methods, such as Computational Fluid Dynamics (CFD), can be implemented for a more detailed approximation.

This work will focus on the calculation of the current transverse drag coefficient necessary to estimate the forces induced by the current on the ship, which are present in the regular docking and departure maneuvers in the port of Bahía Málaga for the frigate Almirante Padilla Class.

This work follows the general recommendations of the model presented in the CFD review studies of MARIN [7] and Lloyds Register (LR) [8] the OCIMF (Oil Companies International Marine Forum) report for current and wind load predictions for VLCC (VLCC) vessels [9] The study presenting the current and wind drag coefficients interacting with the vessel for different angles of incidence on the vessel.

CFD analysis.

It is important to mention that for this analysis only the water flow is considered, paying special attention to the maximum drag coefficient generated by the cross sea current; that is, the one produced when the flow is projected in a normal direction on port or starboard side on the hull. The generalized formula used to obtain the drag coefficient considers the submerged longitudinal area:

$$C_y = \frac{F_y}{\frac{1}{2}\,\rho_w U_{ref}^2 L_{ref} T} \tag{8}$$

Where, U_{ref} represents the fluid velocity, L_{ref} is the length between perpendiculars, T is the draft of the vessel, and Fy is the total force exerted by the fluid on the hull. Also, the dimensionless Froude and Reynolds relationships are applied:

$$R_n = \frac{U_{ref} L_{ref}}{v} \tag{9}$$

$$F_n = \frac{U_{ref}}{\sqrt{g\, L_{ref}}} \tag{10}$$

Where v the kinematic viscosity. All CFD calculations presented in this paper make use of the STAR-CCM+ software tool for CFD simulations.

Table 2. Recommended band according to ITTC.

Scale	L_pp(m)	Re	Tol. (m)
Model	$1 < L_{pp} < 10$	10^6 - 10^7	$^{-5}$
Intermediate	$10 < L_{pp} < 50$	10^7 - 10^8	5 x 10^{-5}
Full	$50 < L_{pp} < 250$	10^8 - 10^9	$^{-4}$

Taking advantage of computational resources, a scale model of the ship is used according to the recommendations of the ITTC (International Towing Tank Conference). [10]. Table 2 shows the recommended scale band according to the Reynolds number of the full-scale ship. The drag formula for the full-scale vessel according to ITTC can be expressed as:

$$C_{TS} = (1+k)\, C_{FS} + \Delta C_F + C_A + C_R + C_{AAS} \tag{11}$$

Where 1+k, represents the shape factor obtained from the channel test, C_{FS} is the friction resistance coefficient, C_R is the residual resistance coefficient,

Δ_{CF} corresponds to the hull roughness factor, C_A is the allowable correlation and C_{AAS} is the air resistance coefficient.

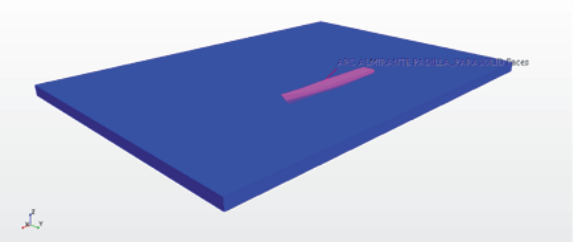
Taking into account equations (9) and (11) and the scaling model recommendations according to ITTC on Table 2, the data configuration of the selected CFD scale model to estimate the drag coefficient is presented in Table 3.

Table 3. Scaled data of the CFD model.

Scale	12,03
L_m	7,481 m
B_m	0,94 m
T_m	0,316 m
Displacement	0.924 tons
V_m	0.1483 m/s
Re_m	1,102 x 10^6
ITTC Reynolds Band	10^6 - 10^7
Fr_m	1,173 x 10^{-2}

The domain size is designated according to the length between perpendiculars for the numerical simulation according to the LR OCIMF report being: 1.5 L for the fore and aft regions, 2 L starboard and 1 L port, an actual depth of 8 meters and a draft of 3.8 meters, which corresponds to the model scale of 0.532 m and 0.316 m respectively.

Fig. 2. Control volume.



Boundary conditions.

As mentioned above, the present study considers the model configuration recommendations described in the MARIN and LR documents. The boundary conditions applied to the model are:

- Domain input: speed input.
- Domain output: pressure output.
- Sides of the domain: sliding wall.
- Domain background: no sliding wall.
- Upper limit of the domain: velocity input.
- Vessel: non-slip surface
- Velocity at the scale model inlet: 0.1483 m/s. (1 knot for the complete ship to scale)
- Free surface: no sliding wall.

As for the recommendations given in the LR OCIMF report, the numerical configuration of the CFD model remains fixed, i.e. without any degree of freedom.

Turbulence model

This study makes use of the K-Epsilon + SST (Shear Stress Transport) model available in STAR-CCM+ with a Y+30 value and a total of 10 prism layers near the hull and over the bottom of the domain to capture the drag effects produced by shallow depth.

Mesh considerations

A mesh model was generated following the general recommendations for a traditional drag simulation (forward flow) without taking into account either the propulsion or steering system.

Additional mesh refinements are included to capture flow behavior near the bow and stern. A control volume is also applied to the free surface, although with a smaller number of cells since the simulation works on a subcritical flow; *i.e.*, a Froude number less than 1, and a negligible wave height, as mentioned in the previously cited published work by MARINE and LR. The implemented mesh configuration can be seen in Figs. 3 and 4.

Fig. 3. Longitudinal view of the hull mesh.

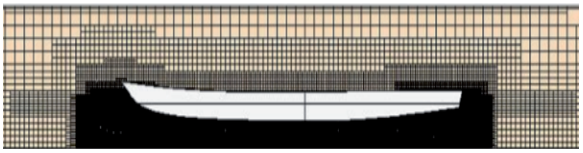
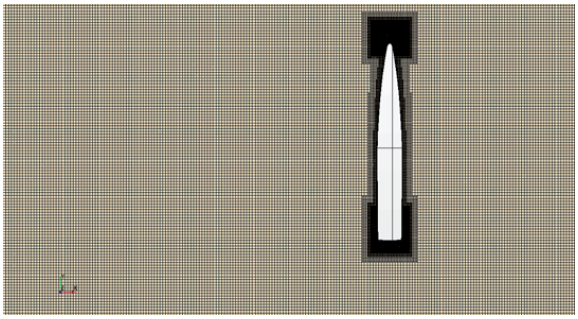


Fig. 4. Top view indicating mesh refinement at the bow and stern of the vessel.



Results.

The Cyc calculation is performed with STAR-CCM+ software, and in order to obtain a stable result of the Cyc coefficient, the recommendations given by the ITTC are applied, which indicate that the flow should cross the domain up to 5 times its size at least. Considering the current velocity of 0.1483 m/s, the minimum simulation time was estimated at about 100 seconds.

The calculated value is obtained from the average of the last 50 seconds, once the simulation result has reached a stable condition (no large fluctuations).

The UFC guidelines establish the following set of equations for estimating the value of the transverse drag coefficient.

$$C_{yc} = C_0 + (C_1 - C_0) \cdot \left(\frac{T}{D}\right)^K \quad (12)$$

$$C_0 = 0{,}22 \cdot \sqrt{X} \quad (13)$$

$$X = L_{wL}{}^2 \cdot \frac{A_m}{(B \cdot V)} \quad (14)$$

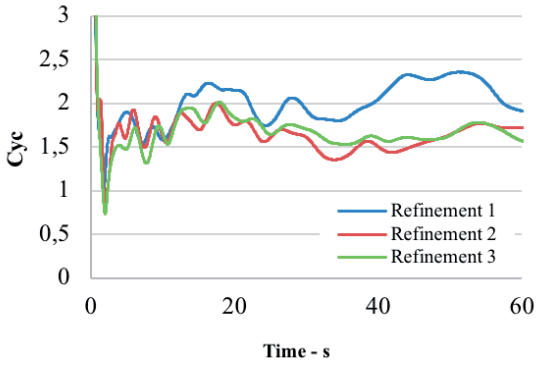
Where, LwL is the length of the vessel at the waterline (m), Am is the submerged cross-sectional area of the vessel at the midsection (m^2), B is the beam at the waterline (m), V is the submerged volume of the vessel, (m^3), C1 is the current force drag coefficient for shallow water where T/d = 1. 0; for currents of 4.9 ft/s (2.9 knots or 1.5 m/s) or less; a value of C1 = 3.2 is recommended, C0 is the drag coefficient for deep water, T is the mean draft of the vessel (m), d is the water depth (m), and K represents a dimensionless exponent obtained from laboratory data from ship models. For this analytical calculation, the value of K =2 is assigned. Table 4 presents the values used for the analytical calculation.

Table 4. Analytical calculation values according to UFC guidelines to obtain Cyc.

Cyc	1,29
X	11,24
C_o	0,737
C_1	3,2
A_m	32,2
C_m	0,748
B (m)	11,3
T (m)	3,8
d (m)	
K	

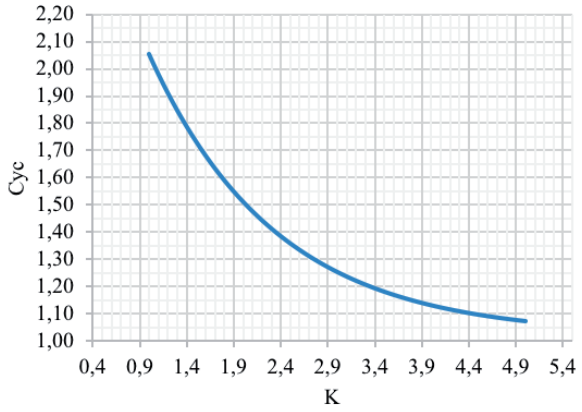
Proceeding to the CFD numerical calculation, the first Cyc coefficient obtained was 2.08, which is considerably higher than the value of 1.29 obtained using the guidelines of the UFC manual.

Fig. 5. Analytical calculation values according to UFC Cyc results over time for different numbers of cells.



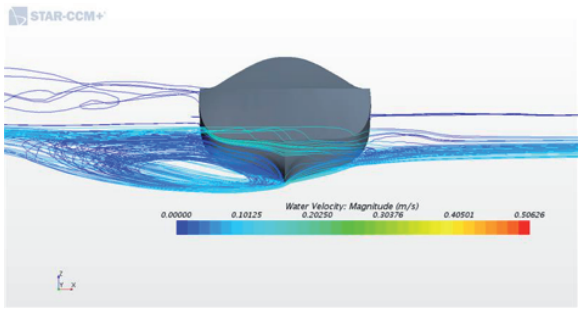
In order to obtain reliable results, a mesh independence analysis is performed. This analysis consists of increasing the number of cells, making a refinement of the mesh in order to reduce the difference of the immediately comparable results obtained from the coefficient.

Fig. 6. Variation of the Cyc coefficient by changing the dimensionless coefficient K and C_0 in equation 12.v



A summary of the Cyc results and the refinement process is shown in Table 5. The time-dependent results of Cyc are observable in the Fig. 5. It is important to note that the results with the analytical CFU methodology differ from the results obtained by simulation due to the absence of a more accurate value of the dimensionless exponent K and C_o for the type of hull presented in this study.

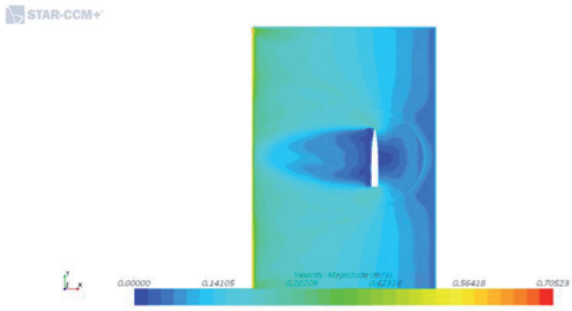
Fig. 7. Stern view showing the presence of vortices.



The Fig. 6 shows the variation of the constant K with respect to the change of the transverse drag coefficient Cyc for the UFC formulation. With a value of Cyc of 1.55, as well as a deepwater drag coefficient C0 of 1.0212 obtained using CFD, the value of K that equals Equation 12 would have a final value 1.9.

The Fig. 7 shows the velocity field obtained from the CFD simulation. The high-pressure zone with vortices can be observed, which increases the total drag force generated by the stream flow, thus increasing the final value of Cyc, as predicted by the CFD results.

Fig. 8. Velocity field (top view).



The Fig. 8 provides the velocity field distribution around the vessel showing zones with low velocity magnitudes, which create a high pressure zone thus increasing the drag coefficient acting on the vessel hull.

Conclusions

The CFD study has been carried out to estimate the drag coefficient Cyc necessary for the calculation of the pulling force required to estimate the required power of the tugboat with the capacity to perform the maneuvering operations to the ships at the naval base of Bahía Málaga, Colombia.

The simulation setup has been performed based on the recommended procedure published in the Lloyds Register OCIMF and the CFU manual for current drag coefficient estimation.

The analytical formulation provided by the UFC manual to calculate the current drag coefficient Cyc, using the predefined constants applicable to general ships and barges, has shown a lower value in magnitude for Cyc compared to that obtained by CFD analysis. This leads to the conclusion that the current drag coefficient calculated using the UFC guidelines may underestimate the current forces, with CFD analysis being a more reliable method for estimating this coefficient.

From the results it can also be concluded that the Cyc coefficient can vary significantly depending

on the hull shape, and in order to use the formulation presented in the UFC manual for the estimation of current induced forces, a safety margin must be included when calculating the required pulling force.

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Analysis of the historical behavior of purchases of goods and services in the repair and maintenance projects of COTECMAR - Bocagrande plant in the last five years

Análisis del comportamiento histórico de compras de bienes y servicios en los proyectos de reparación y mantenimiento de COTECMAR – planta Bocagrande en los últimos cinco años

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Abstract

This research paper is a historical analysis of repair and maintenance purchases for the Corporation of Science and Technology for the Development of the Naval, Maritime and Fluvial Industry - COTECMAR. More precisely, to the projects from Planta Bocagrande. This analysis, searches for aspects to reduce the uncertainty gap in the purchases, through strategic measures, which facilitate the procurement process. The research model is based on the historical data analysis from purchases between 2015 and 2020. It also applies the ABC-XYZ classification, the Kraljic matrix and the criticality levels of the products. The research presents conclusions and recommendations according to the results from the classification and selection of the most relevant materials or products within the purchasing group, chosen following Pareto's law. Considering that the repair and maintenance business line is a market with high uncertainty and variability, adequate planning is required to improve the competitiveness of the services provided to regional shipyards, as a sample of the effectiveness of the capabilities developed by the Colombian shipbuilding industry.

Key words: Analysis, historical behavior, uncertainty, purchases, shipyards, repair, maintenance, products.

Resumen

Este documento de investigación se presenta como un análisis del comportamiento histórico de compras en los proyectos de reparación y mantenimiento en la Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval, Marítima y Fluvial – COTECMAR, más específicamente para los ejecutados en la Planta de Bocagrande. El anterior análisis, se centra en la búsqueda de aspectos que reduzcan la brecha de incertidumbre en las compras, mediante estrategias que faciliten la planeación de las compras. El modelo de investigación está basado en el análisis histórico de las compras por medio de la clasificación de los grupos y productos adquiridos en el periodo de 2015 hasta el 2020 teniendo en cuenta la clasificación ABC-XYZ, la matriz de Kraljic y los niveles de criticidad de los productos. La investigación presenta conclusiones y recomendaciones acordes a los resultados obtenidos a partir de la clasificación y selección de los materiales o productos más relevantes dentro del grupo de compras, escogidos siguiendo la ley de Pareto. Teniendo en cuenta que la línea de negocio de reparación y mantenimiento es un mercado que presenta alta incertidumbre y variabilidad, se requiere una adecuada planeación que permitan mejorar la competitividad de los servicios prestados frente a los astilleros regionales, como muestra de la efectividad de las capacidades desarrolladas por la industria astillera Colombiana.

Palabras claves: Análisis, comportamiento histórico, incertidumbre, compras, astilleros, reparación, mantenimiento, productos.

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Introduction

In relation to its mission and vision, and in the improvement of its strategic plan, The Corporation of Science and Technology for the Development of the Naval, Maritime and Fluvial Industry (COTECMAR), in recent years has implemented strategies to strengthen the attention and satisfaction of its main customer: the National Navy; as well as the reactivation of private customers, in order to further strengthen relations with them, and in turn achieve a better position to its future customers *(Arcieri, 2014)*.

Inventory and purchasing management is considered one of the most complex logistical aspects, since the large investments involved in inventories and the need to control the inventory capital associated with raw materials, product in process and finished product, is perceived as a potential area to contribute to the improvement of the entire supply chain *(Axsäter, 2000)*.

A common problem in inventories is the existence of surpluses and shortages, better known as inventory imbalance, which according to Vidal (2006): "We always have too much of what is not sold or consumed and too much of what is sold or consumed". Inventories are made necessary by random fluctuations in demand and lead times and by the mismatch generated between the demand of end consumers and the production or supply of the products requested *(Juan Miguel Cogollo, 2011)*. Similarly, procurement management requires strategies to anticipate clients' needs and thus guarantee better conditions in terms of cost and delivery time. In order to establish such strategies, the Corporation's purchasing databases make it possible to identify possible patterns in purchasing management.

In this work, the historical behavior of COTECMAR's maintenance and repair purchases in the last five years for the Bocagrande Plant was analyzed to provide information on the possible correlation of purchases by groups of items in specific periods of time. Finally, some considerations that are expected to optimize the logistical support of the Corporation are also given.

Description of the problem

For repair and maintenance projects executed by the Corporation of Science and Technology for the Development of the Maritime and Fluvial Naval Industry - COTECMAR to different clients, the demand for goods and/or services has critical time lines and its planning is limited by the urgency of the repair. For this reason, this type of projects need to identify strategies to anticipate the types of goods or services required.

COTECMAR in its Logistics Manual shows the conditions for support activities for repair projects: "For particular repairs, supply contracts, consignment and field services necessary to ensure continuity in repairs will be established, for this will continue with the strategies outlined in the supply matrix". *(COTECMAR, 2016)*. However, these conditions do not contemplate the anticipation of purchases for the aforementioned maintenance and repair projects.

By performing an analysis based on historical purchases by purchasing groups, it will be possible to identify possible patterns over the last five years that have a significant correlation. This will make it possible to recommend measures to anticipate possible peaks in requirements and provide the Corporation with better cost and time conditions.

Problem formulation

How has the Corporation of Science and Technology for the Development of the Maritime and Fluvial Naval Industry COTECMAR's purchases for the repair and maintenance projects of the Bocagrande plant behaved historically over the last five years?

Justification

Suppliers are the main allies that supply the necessary materials, allowing the development of the required projects, "To achieve the success of an organization includes the selection and management of suppliers of goods and services, the negotiation of prices and purchase terms,

and the acquisition of quality goods and services" *(PILOT, PricewatheratherouseCoopers., 2008)*. The performance of suppliers and of the supply chain in general is determined by the ability to meet demand. Therefore, anticipating demand means an improvement in the conditions for the supply of goods and services, and therefore, an improvement in the capacity to meet projects.

Having tools to improve purchasing processes from the planning stage facilitates logistical support for projects, particularly repair and maintenance projects, and one of these tools is demand forecasting. Given the unpredictability of customer orders, demand management is a key element in effective supply chain management. During the demand management process, the customer's requirements must be balanced with the company's supply capacity by trying to determine what and when they will buy (forecasting). To reduce the level of uncertainty, demand management systems use the most important points of sale and customer databases, which can allow a better efficiency of the physical flow of goods along the supply chain *(Jiménez & Hernández, 2002)*.

For repair and maintenance projects, the forecast of requirements is subject to a high level of uncertainty, which requires a flexible purchasing process. The above consideration is embodied in COTECMAR's logistics manual, "Taking into account the business dynamics, the model for COTECMAR's purchases and logistics, has as its main purpose to adapt to the changing environment of the Corporation, maintaining an organized and defined structure that expands or reduces according to the needs of the organization (High production scenarios and Low production scenarios)." *(COTECMAR, 2016)*. This research presents a historical analysis of project purchases, in order to forecast eventual demand peaks in the purchasing processes for repair and maintenance projects.

COTECMAR in its logistics manual does not currently have tools and / or historical analysis, focused on forecasting requirements for repair and maintenance projects; however, it has enough information to perform such analysis and seek a competitive advantage, thanks to the ERP-SAP system. In COTECMAR this ERP system provides historical purchasing information (type of material, price, business unit, supplier, quantity, among others) since 2014, being currently a fundamental tool in all the processes of the Corporation, evidencing the following: "a company achieves a total competitive advantage in the market if it has an integrated information system throughout the organization, which monitors going through the chain from sales to purchase planning, through the analysis of demand, distribution and production". *(PILOT, PricewaterhouseCoopers., 2008)*.

This research uses information collected and refined from the ERP regarding the purchases of COTECMAR's repair and maintenance projects, for analysis by date, purchase groups, frequency, among others. The results of the previous analysis are presented graphically showing the behavior of the purchases associated to the projects, during the last five years. The conclusion is the identification of the behavior of the groups of purchases for the repair and maintenance projects.

Objectives

General Objective

To analyze the historical behavior of COTECMAR's purchases of goods and services for the repair and maintenance projects at the Bocagrande plant in the last five years.

General Objective

- Compile information by groups of COTECMAR's purchases of goods and services for the repair and maintenance projects of the Bocagrande plant in the last five years.
- Perform product classification, by means of the ABC/XYZ statistical tool, using purchase group history.
- Analyze the main purchasing groups according to the ABC classification, based on historical behavior.
- Select through the Kraljic Matrix the most representative materials of each group and classify them according to their level of criticality.

Methodology

The methodology applied was the comparative-historical method, which deals with the "Procedure of investigation and clarification of cultural phenomena that consists of establishing the similarity of these phenomena, inferring a conclusion about their genetic kinship, that is, their common origin" *(Bernal, 2010). (Bernal, 2010).*

It consists of the collection of the information associated with the purchases of COTECMAR's repair and maintenance projects. This information is treated in order to eliminate possible noise in the data and have cleaner statistics. Likewise, the information was organized by the different groups of purchases, graphing the results obtained in different ways, and thus proceed with the analysis of possible correlation by applying the Pareto diagram and the ABC/XYZ analysis, which allows to know which items generate greater profitability to the company, the variation that they have in a given period and thus make better decisions regarding the supply of each one, which will allow to optimize inventories *(Chackelson, 2010).*

Investigation procedure

The research procedure is carried out by means of the historical-comparative method, which is the procedure of investigation and clarification of cultural phenomena that consists of establishing the similarity of these phenomena, inferring a conclusion about their genetic kinship, that is, their common origin. For this project, the following steps were applied to achieve the proposed objective:

1. Compilation and maintenance of information by groups of COTECMAR's purchases of goods and services for the repair and maintenance projects of the Bocagrande plant in the last five years.
2. Classification of products, by means of the ABC/XYZ statistical tool, using purchase group history.
3. Analysis of the main purchasing groups according to the ABC classification, based on historical performance.
4. Selection through the Kraljic Matrix of the most representative materials of each group and classification according to their level of criticality.

Population and sample

(Bernal, 2010), defines the population as "the set of all the elements to which the research refers." (p.160). When the set is very large, then we proceed to take a representative portion (sample), therefore, in this project we take as population the repair and maintenance projects of COTECMAR; then we take as sample the purchases of goods and services for the repair and maintenance projects in the Bocagrande plant in the last five years.

Techniques and instruments for data collection

For this project, support was requested from the Corporation of Science and Technology for the Development of the Maritime and River Naval Industry (COTECMAR) who provided a document in which the history of purchases from 2015 to 2020 is reported, where the analysis and interpretation of this document was executed taking as a reference for the classification of purchases, Table 1: Purchasing Groups. Additionally, the collection of information through other sources of information such as official documents from public institutions, technical and research reports from public or private institutions, and other secondary sources such as books, articles, research papers.

Results and analysis

Once the information was acquired, a selection and debugging of data that was incomplete due to an inadequate digitalization of the information, and of some items that are not essential in the maintenance and repair processes, such as travel expenses, restaurant expenses, catering, lodging, among others, was carried out. To obtain the results, statistical techniques such as: Inferences, diagrams, correlations of variables, among others,

Table 1. Procurement information by Purchase Groups. Analysis by purchasing groups from 2015 to 2020 for maintenance and repair projects. (ABC XYZ analysis and classification)

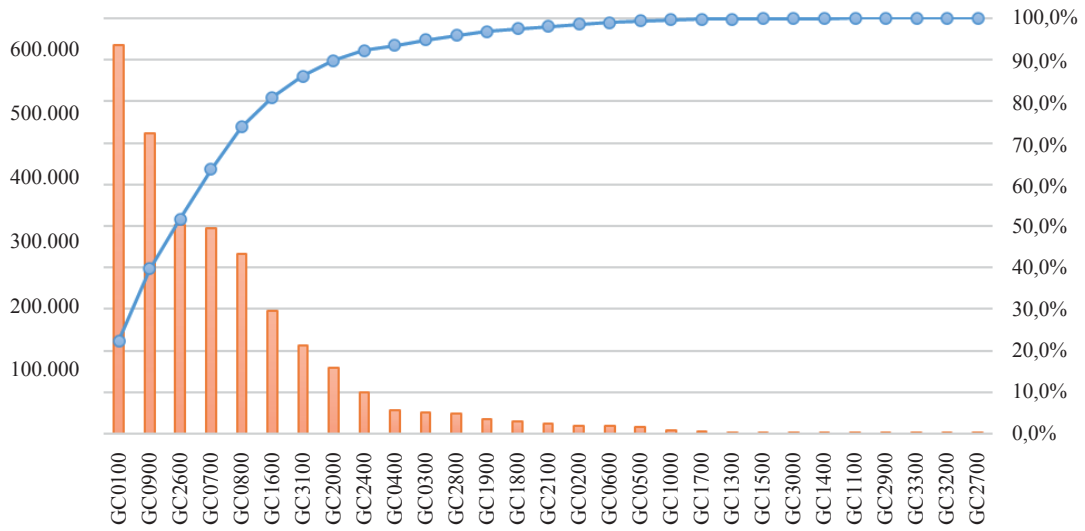
Order Groups	Grand Total	Total Participation	Acumulative percentaje	Ranking ABC	Average	Standard Deriv.	Coef. Variation	Ranking XYZ	ABC_ XYZ
GC0100	608.046	22.378%	22.378%	A	8.445	13.332	1,58	Z	AZ
GC0900	470.416	17.313%	39.691%	A	6.534	4.877	0,75	Y	AT
GC2600	326.740	12.025%	51.716%	A	4.538	11.649	2,57	Z	AZ
GC0700	321.632	11.837%	63.553%	A	4.467	5.169	1,16	Z	AZ
GC0800	280.568	10.326%	73.878%	A	3.897	5.889	1,51	Z	AZ
GC1600	192.737	7.093%	80.972%	B	2.677	3.332	1,24	Z	BZ
GC3100	137.968	5.078%	86.049%	B	1.916	3.676	1,92	Z	BZ
GC2000	102.543	3.774%	89.823%	B	1.424	4.494	3,16	Z	BZ
GC2400	63.807	2.348%	92.172%	B	886	2.037	2,30	Z	BZ
GC0400	36.339	1.337%	93.509%	B	505	2.391	4,74	Z	BZ
GC0300	33.968	1.250%	94.759%	B	472	580	1,23	Z	BZ
GC2800	31.541	1.161%	95.920%	C	438	537	1,23	Z	CZ
GC1900	22.947	0.845%	96.764%	C	319	430	1,35	Z	CZ
GC1800	19.516	0.718%	97.483%	C	271	185	0,68	Y	CY
GC2100	15.735	0.579%	98.062%	C	219	440	2,01	Z	CZ
GC0200	12.695	0.467%	98.529%	C	176	556	3,15	Z	CZ
GC0600	12.561	0.462%	98.991%	C	174	200	1,15	Z	CZ
GC0500	11.089	0.408%	99.399%	C	154	168	1,09	Z	CZ
GC1000	4.851	0.179%	99.578%	C	67	99	1,47	Z	CZ
GC1700	3.480	0.128%	99.706%	C	48	71	1,48	Z	CZ
GC1300	2.188	0.081%	99.786%	C	30	98	3,24	Z	CZ
GC1500	1.671	0.061%	99.848%	C	23	36	1,53	Z	CZ
GC3000	1.383	0.051%	99.899%	C	19	20	1,05	Z	CZ
GC1400	1.312	0.048%	99.947%	C	18	53	2,91	Z	CZ
GC1100	848	0.031%	99.978%	C	12	30	2,57	Z	CZ
GC2900	411	0.015%	99.993%	C	6	10	1,79	Z	CZ
GC3300	94	0.003%	99.997%	C	1	2	1,85	Z	CZ
GC3200	53	0.002%	99.999%	C	1	3	4,04	Z	CZ
GC2700	32	0.001%	100.000%	C	0	4	8,49	Z	CZ
TOTAL	2.717.170	100.000%							

were used to consolidate and graph the information in order to facilitate the analysis.

In the first instance, the information was concentrated by purchasing groups according to Table 1, summing by group, and integrating the number of units from 2015 to 2020. In addition, the share that each group represents among the total units purchased was identified. These groups of purchases correspond to a pre-established classification in COTECMAR, which associates each and every one of the purchases, under a group composed of similar purchases.

Knowing the participation that each group represents, it is analyzed by means of the ABC classification, which allows identifying the product groups with the highest order volume, generating a segmentation of the demand, which is evidenced by the Pareto Principle (Fig. 4) where approximately 20% of the groups represent 80% of the total purchases for the years 2015 to 2020.

Fig. 1. Total Sharings per groups for 2015 to 2020.



Source: COTECMAR. Own elaboration.

ABC Classification

Fig. 2. Groups porcentaje per ranking ABC.

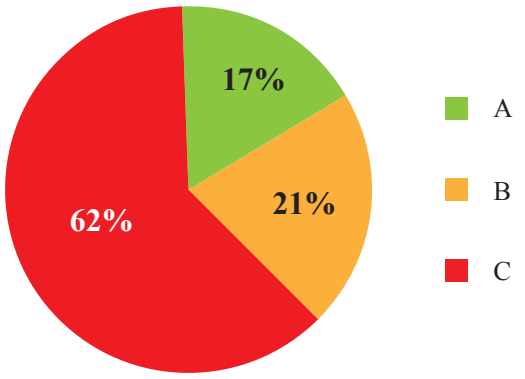
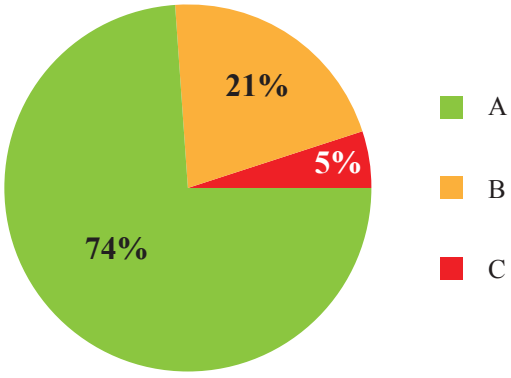


Fig. 3. Sharings in procurments by groups.



Source: COTECMAR. Own elaboration.

Table 2. ABC Classification.

Ranking	Group Numbers	Ranking Percentage	Total Share of purchases
A	5	17%	74%
B	6	21%	21%
C	18	62%	5%
TOTAL	29	100%	100%

Note. ABC classification by total group and share of purchases. Source: COTECMAR. Own elaboration.

By means of the ABC classification (Table 2), a distribution of the groups in three sections is presented, as follows:

Type A groups: there are five groups GC0100, GC0900, GC2600, GC0700, GC0800, which correspond to 17% of the total groups and account for 74% of total purchases.

Type B groups: there are six groups GC1600, GC3100, GC2000, GC2400, GC0400 and GC0300, which correspond to 21% of the total groups and account for 21% of total purchases.

Type C groups: there are 18 groups GC1600, GC3100, GC2000, GC2400, GC0400 and GC0300, which correspond to 62% of the total number of groups and account for 5% of total purchases.

XYZ Classification

The XYZ classification is used to approximately perceive the Volatility of the demand by calculating the Coefficient of Variation (CV= Deviation / Average CV= $\sigma/\mu = \sigma/d$) where they are placed according to the following criteria:

Analyzes demand variability.

X: CV ≤ 0.5 (items with uniform demand)
Y: 0.5 < CV ≤ 1 (items with medium variance)
Z: CV < 1 (items with high variability)

Table 1 shows that most of the groups studied are in the "Z" range where the Coefficient of Variation is greater than 1, with the exception of groups GC0900 and GC1800, which belong to the "Y" set.

ABCXYZ analysis by groups

Taking into account the ABC classification, the analysis is focused on the groups categorized as "AZ" GC0100, GC2600, GC0700, GC0800, (purchases with a high volume of purchases and very unstable demand and high variability) and "AY" GC0900 (high volume of purchases, intermittent demand with medium variability), in order to focus the research on the groups of greatest interest.

Table 3. Demand per PG.

Clase	A	B	C
X	High sales volume, continuous demand, low variability	Average sales volume, continuous demand, low variability	Low sales volume, continuous demand, low variability
Y	High sales volume, intermittent demand, average variability	Average sales volume, intermittent demand, average variability	Low sales volume, intermittent demand, average variability
Z	High sales volume, very unstable demand, high variability	Average sales volume, very unstable demand, high variability	Low sales volume, very unstable demand, high variability

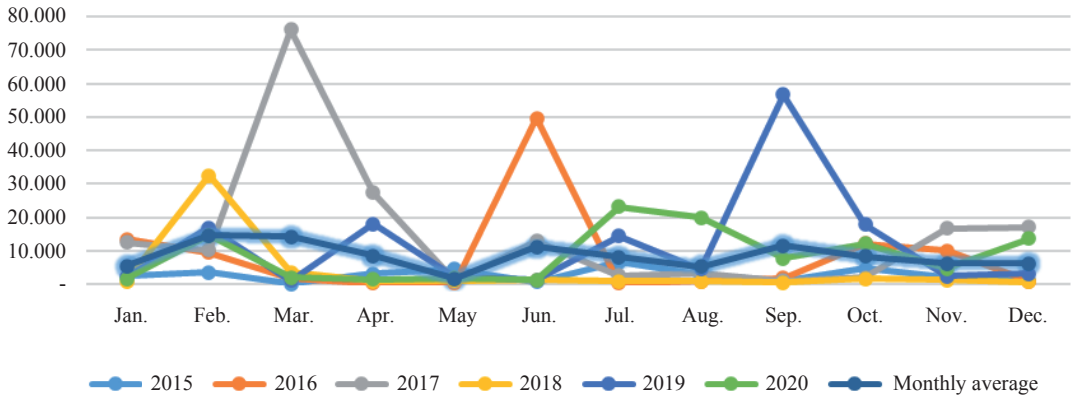
Note. own elaboration, based on (Krzyżaniak S., 2007) & (KaczorowskaZ., 2019) cited in (Żabińska, 2020).

Table 3. Purchases PG GC0100.

GC0100	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	2.340	3.635	201	3.229	4.456	713	6.552	2.755	1.162	4.701	2.013	1.229
2016	13.504	9.504	1.906	407	330	49.720	376	966	1.877	12.208	10.029	975
2017	12.538	10.138	76.153	27.334	829	12.858	2.687	3.136	1.154	1.993	16.690	17.120
2018	906	32.535	3.592	851	1.001	1.308	931	826	565	1.569	1.305	659
2019	2.164	16.838	1.022	18.102	2.014	1.261	14.451	4.518	56.674	17.842	2.461	3.216
2020	1.692	14.520	2.019	1.406	1.762	1.252	23.239	19.866	7.708	12.130	4.791	13.632
Monthly average	5.524	14.528	14.149	8.555	1.732	11.185	8.039	5.345	11.523	8.407	6.215	6.139

Note. Table of the quantity of units purchased monthly of group GC0100 (Abrasives).
Source: COTECMAR. Own elaboration.

Fig. 4. Frequency Polygon 1. Purchases PG GC0100.



Note. Quantity of units purchased monthly from group GC0100 (Abrasives).
Source: COTECMAR. Own elaboration.

With respect to the purchase group GC0100, by means of the Frequency Polygon 1 it can be evidenced that mainly three peaks are represented that exceed forty thousand units purchased the first one in June 2016, followed by March 2017 and finally September 2019, which generates a higher variation coefficient. Also, May is the month with the lowest average number of purchases (1,732) and uniform variability. In addition, in the months of February there is evidence of annual growth in purchases with an average variance with the exception of 2018 in which a peak is shown.

For the GC0900 group, it can be generally observed that it maintains a high volume of purchases with an average variability, although two peaks exceeding twenty thousand units purchased are highlighted, the first one in February 2015 and the second one in June 2016. In addition, for the months of October there is evidence of a smaller deviation in relation to the average.

The group GC2600 of welding articles and industrial gases through the previous Frequency Polygon reflects a high purchase volume with a

Table 4. Purchases PG GC0900.

GC0900	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	1.412	25.850	13.712	7.704	4.591	2.570	13.951	10.118	12.867	7.523	5.377	6.173
2016	892	10.776	9.516	2.086	2.149	23.120	9.087	5.764	1.429	684	316	2.199
2017	338	5.150	2.762	2.138	5.397	2.858	3.220	5.933	6.455	6.174	3.544	1.745
2018	11.871	2.039	3.528	2.982	3.087	1.806	3.860	3.603	13.250	3.542	8.218	5.075
2019	15.243	4.502	8.139	9.836	5.458	8.311	4.518	10.085	7.740	7.472	8.457	1.227
2020	15.243	4.502	8.139	9.836	5.458	8.311	4.518	10.085	7.740	7.472	8.457	1.227
Monthly average	7.500	8.803	7.633	5.764	4.357	7.829	6.526	7.598	8.247	5.478	5.728	2.941

Note. Table of the quantity of units purchased monthly of group GC0900 (Abrasives).
Source: COTECMAR. Own elaboration.

Fig. 5. Frequency Polygon 2. Purchases PG GC0900.

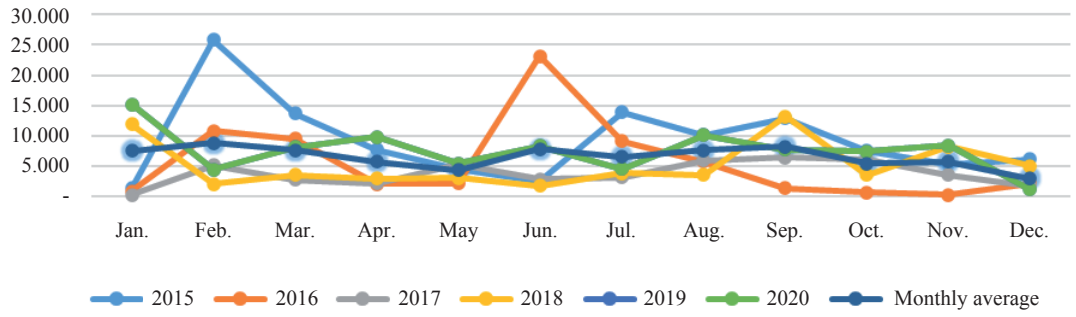


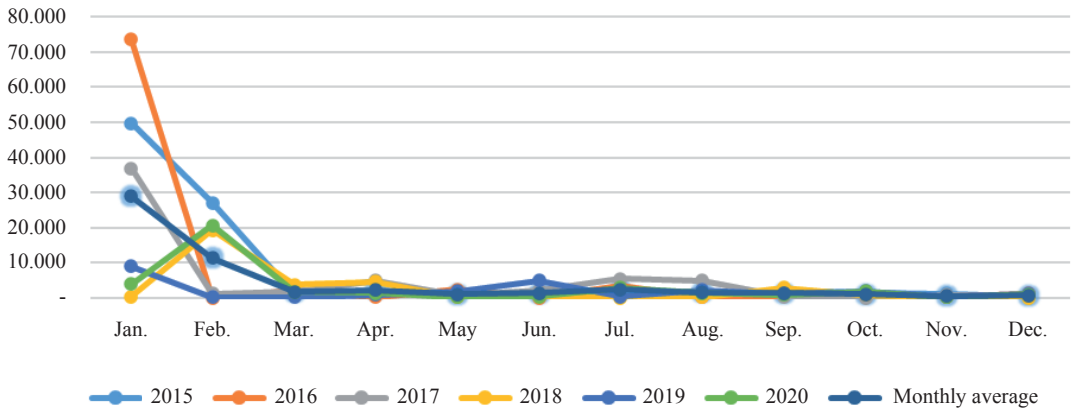
Table 5. Purchases PG GC2600.

GC2600	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	49.676	27.029	1.059	986	1.031	906	2.075	596	2.186	1.598	1.154	590
2016	73.623	112	2.210	201	2.438	33	3.390	176	580	300	349	1.192
2017	39.960	1.248	1.732	4.993	763	2.246	5.374	4.874	354	46	862	546
2018	316	19.336	3.733	4.654	277	185	26	164	2.846	827	231	111
2019	8.928	206	198	840	1.917	4.925	442	2.153	1.228	1.822	294	1.193
2020	3.872	20.698	1.671	1.349	281	357	2.832	1.346	821	1.930	263	984
Monthly average	28.896	11.438	1.767	2.171	1.118	1.442	2.356	1.551	1.336	1.087	525	769

Note. Table of the quantity of units purchased monthly of group GC2600 (Welding and industrial gases).
Source: COTECMAR. Own elaboration.

high variability and an unstable demand. It also highlights a high volume purchasing behavior for the months of January and February accentuated with Greater relevance in the years 2015, 2016 and 2017 exceeding thirty thousand units purchased.

Fig. 6. Frequency Polygon 3. Purchases PG GC2600.



Note. Quantity of units purchased monthly from group GC2600 (Welding and industrial gases).
Source: COTECMAR. Own elaboration.

The GC0700 group shows a high volume of purchases, high variability and unstable demand (Frequency Polygon 4 and Table 6). It is worth highlighting a peak that exceeds twenty-five thousand units for the month of July in the year 20215 and a relationship between the five years for the months of December of these years shows the way in which variability decreases and the purchase volume does not exceed five thousand units.

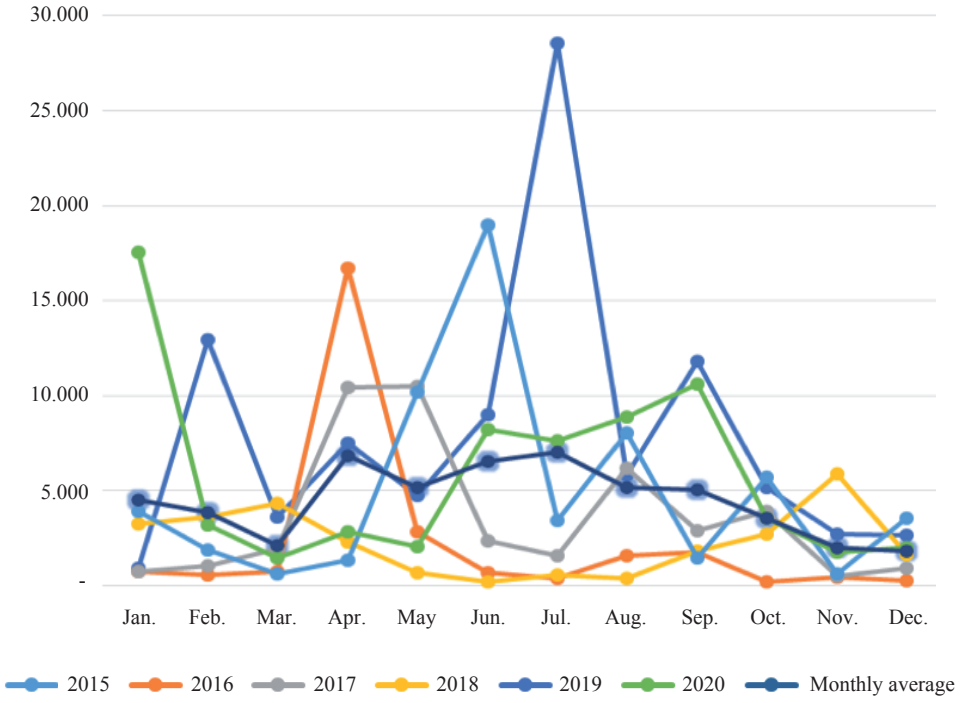
In the purchase group GC0800 of Sheets and Anodes, there is a high purchase volume, high variability and unstable demand (Frequency Polygon 5). It is worth highlighting two peaks that exceed twenty thousand units of purchase, the first one in April 2017 and the month of August 2019. In addition, the month with the lowest level of purchase and the most uniform variability is the month of May at the general level for the years analyzed.

Table 6. Purchases PG GC0700.

GC0700	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	895	12.952	3.604	7.495	4.737	9.019	28.547	5.819	11.790	5.182	2.706	2.655
2016	722	575	734	16.687	2.819	650	353	1.548	1.754	211	415	254
2017	733	1.029	1.906	10.454	10.469	2.348	1.560	6.187	2.864	3.882	499	922
2018	3.249	3.581	4.303	2.273	678	198	557	376	1.791	2.734	5.886	1.634
2019	3.911	1.856	602	1.332	10.183	18.974	3.426	8.059	1.470	5.690	597	3.574
2020	17.542	3.177	1.445	2.848	2.051	8.219	7.610	8.898	10.632	3.555	1.777	1.968
Monthly average	4.509	3.862	2.099	6.848	5.156	6.568	7.009	5.148	5.050	3.542	1.980	1.835

Note.Table of the quantity of units purchased monthly of group GC0700 (Electronic Elements).
Source: COTECMAR. Own elaboration.

Fig. 7. Frequency Polygon 4. Purchases PG GC0700.



Note. Quantity of units purchased monthly from group GC0700 (Electronic Elements). Source: COTECMAR. Own elaboration.

Table 7. Purchases PG GC0800.

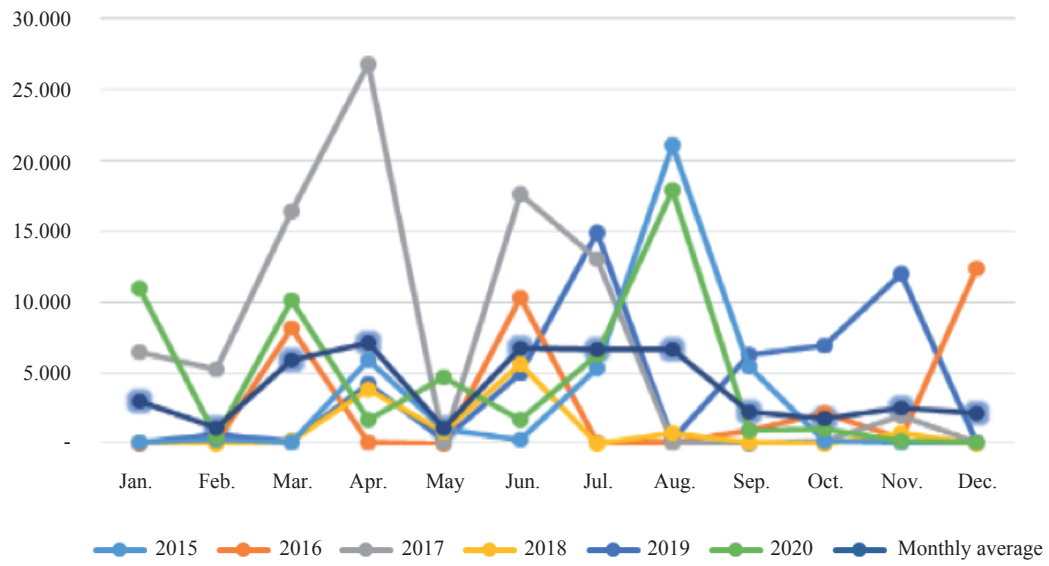
GC0700	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	90	607	222	4.174	245	4.999	14.905	234	6.304	6.880	11.995	95
2016	27	61	8.164	44	23	10.331	65	69	932	2.191	393	12.313
2017	6.478	5.242	16.375	26.782	123	17.603	13.009	44	9	148	1.981	39
2018	128	33	154	3.863	830	5.583	10	695	64	-	776	30
2019	79	254	76	5.848	1.019	266	5.343	21.058	5.390	158	94	74
2020	10.909	426	10.068	1.645	4.650	1.699	6.221	17.845	910	978	142	66
Monthly average	2.952	1.104	5.843	7.059	1.148	6.746	6.592	6.657	2.268	1.726	2.563	2.103

Quantity of units purchased monthly of the GC0800 group. Source: COTECMAR. Own elaboration.

Most Representative Materials

Taking into account the ABC classification applied in the purchasing groups, the most representative materials of each of the groups were identified in order to identify the materials of greatest interest for COTECMAR's repair and maintenance projects.

Fig. 8. Frequency Polygon 5. Purchases PG GC0800.



Note. Quantity of units purchased monthly of the GC0800 group. Source: COTECMAR. Own elaboration.

Table 8. Kraljic matrix of the most representative materials of each group.

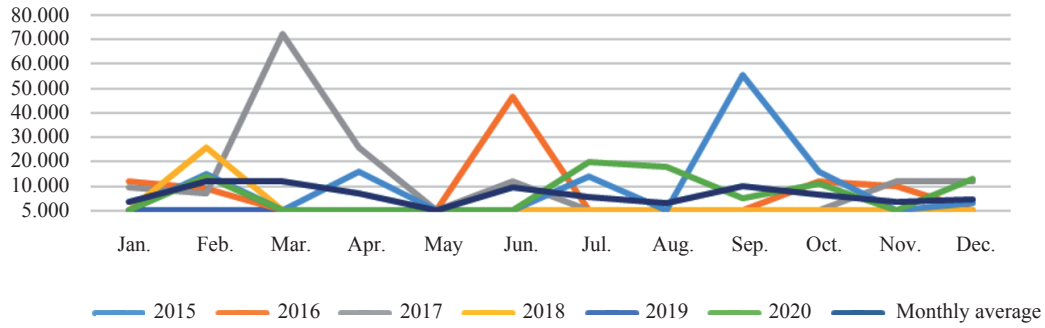
CODE	PRODUCT	FINANCIAL IMPACT	SUPPLY RISK	KRALJIC	CRITICALITY
120000400	Slag Mineral Abrasive Shot	Low	Low	Routine or Tactical	Essential
110000139	Sheet A/N ASTMA-131 1/4" 8x20' 740.01 kg	High	High	Strategic	Vital
130000072	Oxígeno líquido	High	High	Strategic	Vital
120000806	Screw Phillips Drywall DIN7505 #8 x 2"	Low	Low	Routine or Tactical	Essential
120001104	Black Plastic Clamp 14"	Low	Low	Routine or Tactical	Essential

Note. Kraljic matrix of the most representative materials of each group and classification of criticality level. Source: Own elaboration.

GROUP GC0100 ABRASIVES - MATERIAL 120000400 SLAG MINERAL ABRASIVE SHOT

According to the frequency polygon 6, there are three representative purchasing peaks which exceed forty thousand units, the first one is in June 2016, the second one in March 2017 and the last one in September 2019. In addition, according to the Kraljic matrix, the material Slag Mineral Abrasive Shot is classified as a routine or tactical product, it also has a criticality of essential character generally for maintenance and repair and maintenance projects.

Fig. 9. Frequency Polygon 6. Purchases of material 120000400.



Note. Quantity of units purchased monthly in the last five years of Slag Mineral Abrasive Shot.
Source: COTECMAR. Own elaboration.

Table 9. Purchases for items of code 120000400.

120000400	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	0	0	0	0	0	0	0	0	0	0	0	0
2016	12000	9000	0	0	0	46500	0	0	0	12000	10000	0
2017	9500	7000	72000	26000	0	12000	0	0	0	0	12000	12000
2018	0	26000	0	0	0	0	0	0	0	0	0	0
2019	0	15000	0	16000	0	0	14000	0	55500	16000	0	3000
2020	0	14000	0	0	0	0	20000	18000	5000	11000	0	13000
Monthly average	3.583	11.833	12.000	7.000	-	9.750	5.667	3.000	10.083	6.500	3.667	4.667

Note. Table of Quantity Units purchased monthly for items of code 120000400 (Slag Mineral Abrasive Shot).
Source COTECMAR. Own elaboration.

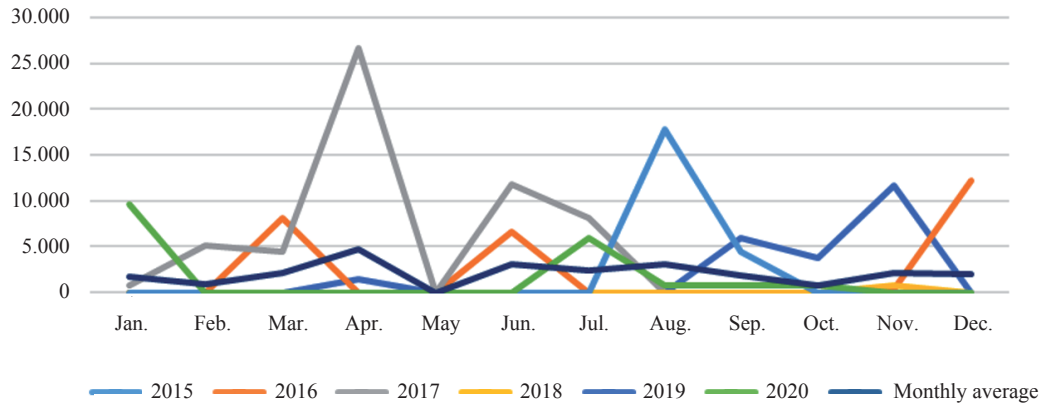
GROUP GC0800 LAMINATES AND ANODES - MATERIAL 110000139 LAMINATE A/N ASTMA-131 1/4" 8X20' 740.01KG

This product presents a high level of uncertainty, but has a considerable volume of units purchased in the second half of the last three years. In addition, according to the Kraljic matrix, we can see that this product is classified as strategic, and has a vital criticality characteristic within the maintenance and repair projects.

WELDING ITEMS AND INDUSTRIAL GASES GC2600 - MATERIAL 130000072 LIQUID OXYGEN

This material presents a purchasing behavior mostly inclined to the months of January and February with representative volumes. In addition, according to Kraljic's matrix, it is classified as a strategic material, and with a criticality characteristic of vital character within the maintenance and repair projects.

Fig. 10. Frequency Polygon 7. Purchases of material 110000139.



Note. Quantity of units purchased monthly in the last five years of ASTMA-131 1/4" 8X20' 740.01KG A/N ASTMA-131 sheet 740.01KG. Source: COTECMAR. Own elaboration.

Table 10. Purchases for items of code 110000139.

110000139	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	0	0	0	1480,02	0	0	0	0	5920,08	3700	11662,9	0
2016	0	0	8140,11	0	0	6660,09	0	0	0	0	370,005	12210,1
2017	740,01	5180,07	4440,11	26644,36	0	11840,16	8140,11	0	0	0	0	0
2018	0	0	0	0	0	0	0	0	0	0	740,01	0
2019	0	0	0	0	0	0	0	17761	4444	0	0	0
2020	9620	0	0	0	0	0	5938,86	741,93	749	749	0	0
Monthly average	1.727	863	2.097	4.687	-	3.083	2.346	3.084	1.852	742	2,129	2.035

Note. Table of Quantity Units purchased monthly for items of code 110000139 (ASTMA-131 1/4" 8X20' 740 A/N ASTMA-131 sheet). Source COTECMAR. Own elaboration.

Fig. 11. Frequency Polygon 8. Purchases Items 130000072 Liquid Oxygen.

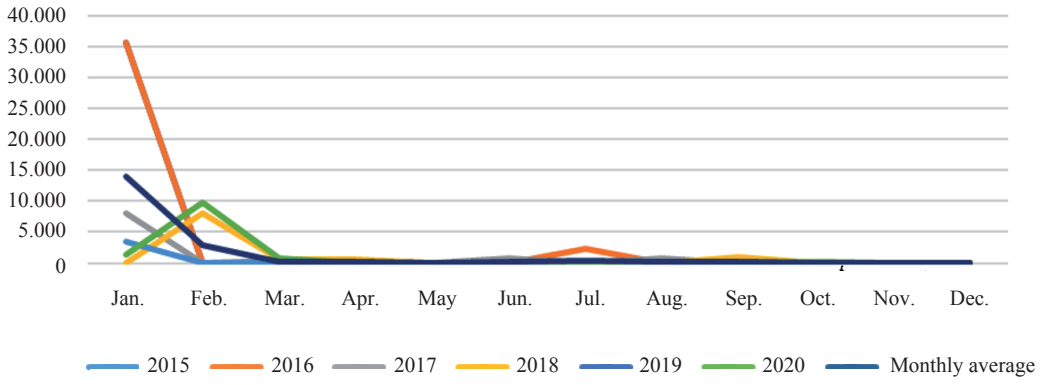


Table 11. Purchases for items of code 130000072.

130000072	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	35680	0	0	345	0	0	260	0	0	0	0	0
2016	35680	0	0	0	0	0	2405	0	0	0	0	0
2017	8100	0	404	0	0	800	0	714	0	0	0	0
2018	0	8100	520	520	0	0	0	0	1040	0	0	91
2019	3480	0	0	0	0	0	130	0	130	0	0	0
2020	1441	9749	780	0	0	0	0	0	0	130	0	0
Monthly average	35680	0	0	345	0	0	260	0	0	0	0	0

Note. Table of Quantity Units purchased monthly for items of code 130000072 (Liquid Oxygen).
Source COTECMAR. Own elaboration

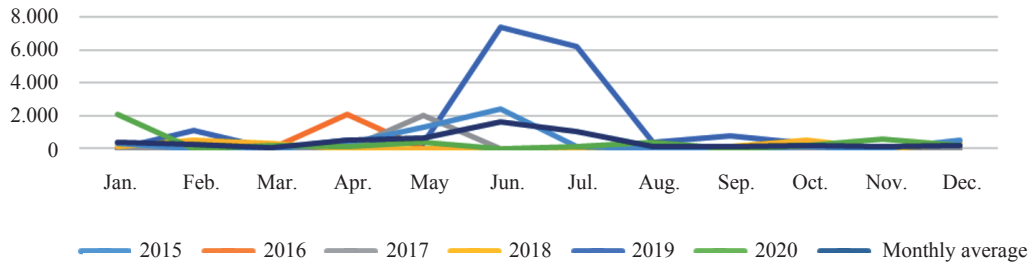
GC900 SCREWS, NUTS AND WASHERS - MATERIAL 120000806 PHILLIPS DIN7505 #8 X 2" DRYWALL SCREW

This material, through the frequency polygon 9 shows us that it has a behavior focused on the second semesters of the years under study, and with peaks in 2015 for the months of March and July, in 2020 it presented a considerable growth in the second half of the year. In addition, according to the Kraljic matrix, this material is classified as routine or tactical, and a level of criticality denominated as essential within the maintenance and repair projects.

ELECTRONIC ELEMENTS GC0700 - MATERIAL 120001104 BLACK PLASTIC CLAMP 14

This reference, shows constant purchases with low volumes distributed in most months, and a large peak in 2019 for the month of June. In addition, it is classified according to the Kraljic matrix as a routine or tactical material, and a level of criticality denominated as essential within maintenance and repair projects due to the abundance of supply in the market.

Fig. 12. Frequency Polygon 8. Purchases Items 120000806.



Note. Table of Quantity Units purchased monthly for items of code 130000072 (Liquid Oxygen).
Source COTECMAR. Own elaboration

Table 12. Purchases for items of code 120000806.

120000806	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	0	2500	5000	0	0	0	5000	0	0	0	1000	0
2016	0	0	0	0	0	0	1000	600	0	0	0	0
2017	0	1600	0	0	0	0	0	400	0	4000	0	0
2018	0	0	0	200	0	0	0	0	600	0	0	0
2019	0	0	200	0	0	0	800	0	0	0	0	0
2020	0	0	0	0	0	1700	2609	2300	1500	3800	300	0
Monthly average	0	683	867	33	0	283	1568	550	350	1300	217	0

Note. Table of Quantity Units purchased monthly for items of code 120000806 (Drywall Screw Phillips Din7505 #8 X 2"). Source COTECMAR. Own elaboration.

Table 13. Purchases for items of code 120001104.

120001104	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	0	1100	0	500	300	7400	6200	400	800	0	1100	0
2016	0	0	0	2100	0	0	0	0	0	0	0	0
2017	0	0	0	0	2000	0	0	0	0	0	0	0
2018	100	500	300	0	0	0	0	100	100	100	500	300
2019	300	0	0	300	1300	2400	100	0	0	300	0	0
2020	2103	0	200	130	400	0	100	400	1	2103	0	200
Monthly average	417	267	83	505	667	1.633	1.067	150	150	417	267	83

Note. Table of Quantity Units purchased monthly for items of code 120001104 (Black Plastic Clamp 14). Source COTECMAR. Own elaboration.

Conclusion

In this work was performed, the analysis of the historical behavior of the purchases of goods and services of COTECMAR for the repair and maintenance projects Bocagrande plant in the years from 2015 to 2020, it was essential for this analysis to collect information by groups of purchases which was provided by COTECMAR; however, during the research it was evidenced that some data were wrong, reducing the accuracy of the results. Therefore, the importance of the adequate use of the information systems is highlighted, as well as the verification of the training of the personnel that manages them, and the standardization of the processes.

In addition, using the ABC/XYZ tool, evidence was obtained that the behavior of purchases follows the Pareto rule, where 17% of the

purchasing groups have a share of 74% of the total number of units purchased, therefore, the demand for them is more relevant.

It was also ratified by means of the ABC/XYZ classification that these purchases highlight a behavior aligned to an uncertainty market, given that the volatility of demand could be perceived in an approximate way by means of the variation coefficient. For example, 93.1% of the groups are classified in the "Z" set, indicating high variability, and 6.9% in the "Y" set, indicating medium variability.

By means of the ABC classification, the behavior of the purchase history is analyzed, highlighting the importance of group "A", which contains groups GC0100, GC0900, GC2600, GC0700, GC0800, and therefore its behavior is analyzed graphically, concluding that there is a high variability and it does not show a marked seasonality of demand, nor a punctual and stable correlation in the years studied. However, it is necessary to carry out a more detailed follow-up by product to analyze each case in isolation and evaluate the characteristics that affect it.

In the case of group GC0100 (Abrasives), it was identified as the group with the highest participation, although it has a high variability, mainly characterized by purchases of more than ten thousand units in the month of February, so it is recommended as a minimum to make purchases for this month according to the average: 5,524 units. Also for the aforementioned group, a low level of purchases is observed in the month of May, with an average of 1,732 units, so it should be taken into account in the purchase planning. In addition, since this group has a high volume of purchases, the feasibility should be studied to generate alliances with suppliers that allow me the availability of products at a fair price.

One of the limitations found in the research was the large number of products, so the analysis was carried out by groups. However, it would be valuable for decision making to calculate the reorder points, time averages of average supply periods, storage costs, safety stock, among others, for each product that will allow you to have greater control over inventories. Within the most representative materials can be highlighted in each group according to Pareto's law as follows:

1. GC0100Abrasives - material 120000400 abrasive mineral slag abrasive grit
2. GC0800 Sheet and anodes - material 110000139 sheet a/n astma-131 1/4" 8x20' 740.01kg
3. GC2600 Welding items and industrial gases - material 130000072 liquid oxygen
4. GC900 Screws, nuts and washers - material 120000806 screw drywall screw Phillips din7505 #8 x 2".
5. GC0700 Electronic elements - material 120001104 black plastic clamp 14"

These materials are classified according to Kraljic's matrix as: routine or tactical (numbers 1, 4, and 5) due to the high levels of supply in the market or the ease of procurement and with an essential criticality level. And as strategic (numerals 2 and 3) due to their high procurement risks and high financial costs and with a vital criticality level due to the importance in maintenance and repair projects.

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The text must be explanatory, clear, simple, precise, and original in presenting ideas. Likewise, it must be organized in a logical sequence of parts or sections, with clear subtitles to guide readers. The first part of the document is the introduction. Its objective is to present the theme, objectives, and justification of why it was selected. It must contain sources consulted and methodology used, as well as a short explanation of the status of the research, if it were the case, and form in which the rest of article is structured.

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

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

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