SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

COTECMAR
COLOMBIA

POC

OCEAN PATROL VESSEL

ISSN 1909-8642 (Impreso)
ISSN 2619-645X (Online)

Vol. 17 - N.° 34
(1 - 66) January 2024

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Volume 17, Number 34 - January 2024 ISSN 1909-8642 (Impreso) - ISSN 2619-645X (Online)

Ship Science & Technology is a specialized journal in topics related to naval architecture, ship design, hydrodynamics, dynamics of ships, structures and materials, vibrations and noise, technology of ship construction, ocean and marine engineering, standards and regulations, oceanography, maritime and river transport, and port infrastructure. Every six months, the journal publishes scientific papers that constitute an original contribution in the development of the mentioned areas, resulting from research projects of the Science and Technology Corporation for the Naval, Maritime and Riverine Industries, and other institutions and researchers. It is distributed nationally and internationally on paper and online.

A publication of
Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval, Marítima y Fluvial - COTECMAR
Electronic version: www.shipjournal.co

COTECMAR
COLOMBIA

Editorial Coordinators Jymmy Saravia Arenas M.Sc
Adriana Lucía Salgado Martínez M.Sc

Layout and design Mauricio Sarmiento Barreto

Cover image designed by Vladimir González Castiblanco

Printed by C&D Publicidad & Marketing. Bogotá, D.C.

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES
Volume 17, Number 34 - January 2024 ISSN 1909-8642 (Impreso) - ISSN 2619-645X (Online)

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Editorial Note

Cartagena de Indias, January 31st, 2024.

Welcome everyone to this 2024 first edition of our Ship Science and Technology magazine; We hope that, for each of our readers, their families and institutions, this new year will be full of achievements and success in every sense.

This year will be crucial for our corporation, we will advance in the final stages of the construction of the first Colombian Ocean Patrol Vessel (POC), as well as in the advanced phases of the design of the first ship of the Colombian Frigate PES (Strategic Surface Platform Project) among other strategic challenges that will contribute to continue positioning us as a leading shipyard at a national and regional level.

For this edition, we compile articles of professional interest on different topics, such as: Shipyard's Quality System involvement in the classification process at the new construction phase; the Challenges in the systems integration process in naval units. Case of study: Data Distribution Unit Project; Perspectives for the development of unmanned surface vehicles in Colombia: COTECMAR case; Barriers and enablers for developing sustainable supply chains in the shipbuilding industry and finally, the Decision-making model for propulsion system selection.

Now we are starting the planning for our International Naval Engineering Congress CIDIN 2025, an event that we will develop within the framework of the Twenty-Fifth Anniversary of our Corporation; We will be telling you about its progress and from now on.

Everyone is invited. We are waiting for you.

At COTECMAR, "We're Moving Forward".

Cordially,

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

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Nota Editorial

Cartagena de Indias, 31 de enero de 2024.

Bienvenidos todos a esta primera edición de 2024 de nuestra revista Ciencia y Tecnología de Buques; esperamos que, para cada uno de nuestros lectores, sus familias e instituciones, este nuevo año sea lleno de realizaciones y logros en todo sentido.

Este año será crucial para nuestra Corporación, avanzaremos en las etapas finales de la construcción de la primera Patrullera Oceánica Colombiana (POC), así como en las etapas avanzadas del diseño del primer buque de la clase de la Fragata Colombiana (Proyecto Plataforma Estratégica de Superficie) entre otros desafíos estratégicos que contribuirán a seguir posicionándonos como un astillero referente a nivel nacional y regional.

Para esta edición, compilamos artículos de interés profesional sobre diferentes temáticas, como son: la Participación del Sistema de Gestión de Calidad de un Astillero durante el proceso de clasificación en fase de construcción, los Desafíos en el proceso de integración de sistemas en unidades navales. Caso de estudio: Proyecto Unidad de Distribución de Datos, las Perspectivas para el desarrollo de vehículos de superficie no tripulados en Colombia: El caso de COTECMAR, las Barreras y facilitadores para la implementación de cadenas de suministro sostenibles en la industria naval y finalmente, el Modelo de toma de decisiones para la selección del sistema de propulsión.

Iniciamos desde ya, el planeamiento para nuestro Congreso Internacional de Ingeniería Naval CIDIN 2025, evento que desarrollaremos en el marco del Vigésimo Quinto Aniversario de nuestra Corporación; les estaremos contando de sus avances y desde ya, todos están invitados.

Los esperamos.

En COTECMAR, “Seguimos Avante”.

Cordialmente,

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

Shipyard's Quality System involvement in the classification process at the new construction phase

Participación del Sistema de Gestión de Calidad de un Astillero
durante el proceso de clasificación en fase de construcción

DOI: https://doi.org/10.25043/19098642.245

Lina Suárez [1]

Abstract

The Quality Management System (QMS) of a shipyard is considered as a dynamic system which ameliorates in parallel with the evolution of the shipyard, having as purpose to optimize construction performance, to reduce risks, costs and time. The interaction and participation with external organizations play an important role in the cycle processes of maintenance and improvement of the Shipyard QMS. Bureau Veritas (BV) being a Ship Classification Society, contributes to the certification process through compliance with regard to BV technical rules and statutory requirements for each ship configuration. This paper illustrates the importance of the interaction between shipyard and class society starting at early design phase until delivery of the ship. Process described is based on specifics BV rules and New Building procedures which are continuously updated based on new international regulations, experiences, researches and developments. The pre-project process is founded on the definition of the scope of work, a thorough review of the contract, familiarization with the shipyard's facilities, and the definition and agreement of all activities to be addressed throughout the entire construction. The construction process unfolds according to the agreements outlined during the pre-project phase. This part is specifically concentrated on Design Review (drawings and documents), Documentation System (procedures and methods), the Verification System (monitoring, control & reporting, witnessing, inspection & test), and the Management System (but not limited to); all of which are managed under a specific BV IT Tool. The result of all this is an efficient classification process that ensures ships remain safe, compliant, efficient, and environmentally friendly throughout their operating life.

Key words: Quality Management System, Ship Classification Society, Classification rules

Resumen

El Sistema de Gestión de la Calidad (SGC) de un astillero se considera como un sistema dinámico que mejora simultáneamente con la evolución del astillero, y cuyo objetivo es optimizar la ejecución de la construcción, reducir los riesgos, los costos y tiempos. La interacción y participación conjunta con organizaciones externas también desempeñan un papel importante en los procesos del ciclo de mantenimiento y la mejora del SGC del Astillero. Bureau Veritas (BV) en su papel como Sociedad de Clasificación, contribuye al proceso de certificación mediante el cumplimiento de las normas técnicas propias y los requisitos legales para cada configuración de barco. Este artículo refleja la importancia de la relación mutua entre el astillero y la sociedad de clasificación desde la fase inicial de diseño hasta la entrega del barco. El proceso descrito se basa en la normativa de BV y procedimientos de nuevas construcciones las cuales se actualizan apoyados en nuevas normativas internacionales, experiencias, investigaciones y desarrollo. El proceso de anteproyecto se basa en la definición del alcance del trabajo, la revisión del contrato, la familiarización con las instalaciones del Astillero, la definición y el acuerdo frente a todas las actividades que se abordarán durante el proceso de construcción. Dicho proceso se realiza según los acuerdos enumerados durante el anteproyecto y se focaliza en la revisión del diseño (planos y documentos), el sistema de documentación (procedimientos y métodos), el sistema de verificación (monitoreo, control e informes, observación, inspección y actividades de pruebas) y el Sistema de Gestión (sin limitación a lo mencionado anteriormente); todo se gestiona utilizando una herramienta informática propia de BV que ha sido desarrollada para este propósito. El resultado, es un proceso eficaz de clasificación que mantiene a los barcos seguros, conformes a las normas, eficientes y respetuosos con el medio ambiente durante la totalidad de su vida operativa.

Palabras claves: Sistema de Gestión de la Calidad, Sociedad de Clasificación de Buques, Reglas de clasificación.

Date Received: October 14th, 2022 - *Fecha de recepción: 14 de octubre 2022*
Date Accepted: February 10th, 2023 - *Fecha de aceptación: 10 de febrero de 2023*

[1] Bureau Veritas - Marine & Offshore, New Construction Management. Paris, France. Email: lina.suarez@bureauveritas.com

Introduction

The Quality Management System in a shipyard has the primary objective of achieving a zero-defect rate through the definition of processes, including controls, records, validations, measurements, analysis, monitoring, and improvements. This makes the QMS an integral part of a strategy to enhance market position and customer satisfaction.

The quality process must be established using standard procedures and methods, which need to be consistently followed throughout the entire process of the physical product, such as the construction of the ship.

Such a process must include targets related to the limits of acceptance for each specific process. The system's control involves documentation such as construction procedures, fabrication drawings, technical analysis reports, weight control reports, subcontractor documents, and as-built documentation, among others.

Quality records encompass contract reviews, drawings, procedures, inspection and test records, verification records, pre-commissioning, calibration records, material and equipment certificates, non-conformities, commissioning dossiers, among others.

The validation process in production includes monitoring or verification of welder certification, welding procedures, welding machines, welding consumables, NDT operator certification, NDT plan, and NDT reports, among others.

Measurement analysis and improvement aim to demonstrate the conformity of the quality management system and the quality of the product. This involves a quality audit plan, control of non-conformities, management reporting, corrective actions necessary to improve the system, and client feedback.

This article aims to emphasize the importance of defining, planning, and reaching agreements at an early stage by integrating all the mentioned activities and ensuring continuous follow-up within cross-functional processes during construction. This approach is based on the extensive knowledge and experience in high-quality standards gained since 1828 in the shipping industry.

Pre Project Process

The classification process involves the definition of rules, guidance notes, and other relevant documents for a ship, taking into account its structure, material, machinery, equipment, and other components contributing to its definition.

This process includes the review of plans/documents, calculations, surveys, checks, verification, validations, witnessing, and tests intended to demonstrate that the ship complies with the BV rules and applicable statutory requirements.

For Bureau Veritas, the key to achieving the classification process in new construction is to identify and agree with the client on the scope of work. It is essential to possess a comprehensive understanding of the shipyard's capacities and to reach consensus on every activity to be followed during the construction, as illustrated in Fig. 1.

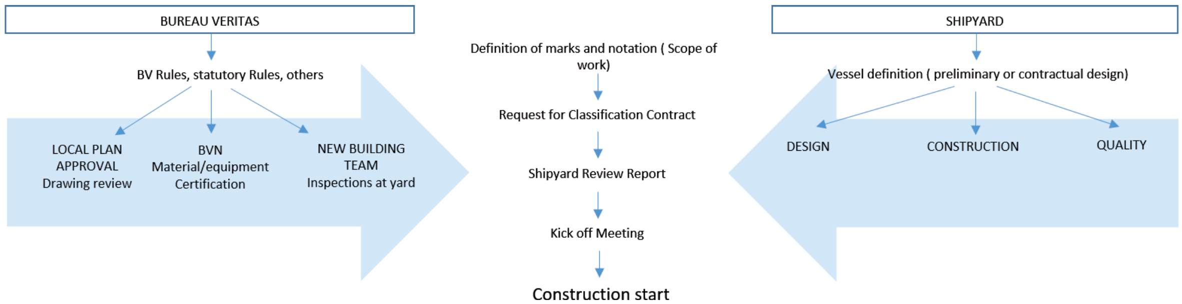
Definition of marks and notations

The class notations establish the framework upon which the ship's classification is founded. They reference specific rule requirements that must be adhered to for their assignment. Class notations are specifically allocated based on the ship's type, service, operating area, and other criteria outlined by the interested party when applying for classification.

The types of class notations to be assigned to a ship are as follows:

- Class Symbol: Indicates the degree of compliance of the ship with the rule requirements concerning its construction and maintenance.
- Construction Marks: Identifies the procedure under which the ship and its main equipment

Fig. 1. Workflow at pre-project phase between Bureau Veritas and Shipyard.



or arrangements are to be surveyed for the initial assignment of the class. It is assigned separately to the hull of the ship and its appendages, to the machinery installation, and to some other installations for which an additional classification notation can be added.

- Service Notation: Defines the type and/or service of the ship considered for its classification.
- Additional Service Features: Provide further precision regarding the type of service of the ship, as applicable.
- Navigation Notations and Operating Area Notations: Assigned to limit the operational zone, as applicable.
- Additional Class Notations: Specify the classification of additional equipment or specific conditions/installations, as applicable.

Classification Request

It is the technical contract between the shipyard and the classification society. This document identifies the client's inquiry and outlines key items to initiate the classification process.

1. General description:

a. RFC data: client data (designer, shipyard and/or shipbuilder). Local Plan Office designed for each system as Hull, Machinery, Refrigeration, Electricity, Automat, Safety, Cargo cont, Intact Stability and Damage Stability.

b. Remarks and/or Follow-up comments

2. General data:

a. Identification: hull number, ship name, leader/ sistership /quasisistership identification, type and service, flag (military included), option of dual/double class, BV construction office, yard subcontractor, registered and commercial owner, designer, manager, commercial BV offices.

b. Schedule: contractual dates, declaration data of contract (definition of rules version)

c. Definition of marks and notations (construction marks, classification symbols, service notations, additional service feature, navigation notation, operating area notation, etc)

d. Additional notations and additional information (as applicable)

3. Ship details:

a. Hull: dimensions and characteristics, important details as lifting appliances, transport capacity, refrigeration installation, number of persons on board, etc.

b. Machinery: propulsion type, propulsion power, contract speed, electrical power, engines and generators details, etc

c. Propellers: propulsor type, propeller material, manufacturer, license, tail shaft type, bearing type, shaft diameter, shaft material, location on board, survey, stern tube lining, tail shaft seal, shaft coupling, shaft configuration, etc.

d. Automation characteristics for

i. Main propulsion: main engine type, number main engines, crosshead engine, reduction gear, etc

ii. Auxiliaries: number of generators, number of shaft driven generators, number of starting/control air compressor, fresh water generator, etc.

4. Annexes (as applicable):

a. List of statutory attestations/ certificates

b. List of statutory documents without survey (Stability examination, attestations)

Shipyard Review Record

This document is prepared to familiarize with the shipyard's production facilities, management processes, and safety considerations. During this initial approach, BV aims to understand the shipyard's capability to meet contractual requirements before initiating any new construction. The following items need to be considered: Detail of any management systems : ISO standards or others

1. Construction facilities: identification

a. Building Berth or Dock (name, dimensions, capacity (GT), cranes)

b. Outfitting quays (name, dimensions, berthing capacity (GT), cranes)

c. Main fabrication and erection facilities

i. Marking and cutting of steel plates

ii. Marking and cutting of section bar

iii. One-side automatic welding machine

iv. Fillet welding machine gravity or automatic and percentage of automatization for this last one

v. Painting equipment

vi. Vertical automatic welding machine

vii. Other main fabrication facilities

2. Shipyard control of qualified welders for shipyard workers and/or subcontracted workers (certification, traceability, supervision, maintenance of qualification).

3. Feature of construction procedure

a. Subcontract of hull blocks (weight): Sub members and blocks (ratio of subcontracted works and number of subcontractors)

b. Method of plate block assembly: method fitting and welding longitudinal and transverse webs on jointed panels; method welding longitudinal on jointed panels prior to fitting and welding transverse webs; method fitting and welding a frame consist of longitudinal and transverse webs on jointed panels ; method jointing panels with pre-assembled longitudinal by welding prior to fitting and welding transverse webs ; other

c. Pre-erection outfitting carried out, grand block/mega block adopted & method of erection at building berth/dock: max weight of loading block (tons); construction method in building dock/ berth/land construction (1 ship, 1.5 ships: semi-tandem, dual entrance); block loading process (single starting block, multi starting blocks, inserting block).

d. Final dock : in house or other

e. Other feature of construction procedure

4. Quality Control System

a. Existence of the organization chart including the departments of design, purchasing, manufacturing and quality assurance

b. Quality control organization: number of employees within the organization, existence of procedures or plans related to test and inspections

c. Pre-inspection system of shipyard: pre-inspection carried out prior to class inspection; pre-inspectors assigned; number of pre-inspectors (related to hull only); records of pre inspections results; acceptance of pre-inspections if subcontracted.

d. Record of inspections and test: records made and recorded; adoption of necessary corrective actions against Non-Conformities; acceptance of pre-inspections if subcontracted.

e. Condition at the time of the surveys in the presence of class surveyors: schedule, pre-inspections, shipyard inspections and repairs completed beforehand; sufficient preparation for surveys such as scaffoldings, lighting, cleaning made.

5. Measures for safety and health

a. Conditions of scaffolding, nets, safety belt, lighting and ventilation

b. Radiographic examination and operations of cherry picker

6. Control system of Non-Destructive Examinations (NDE)

a. Number of NDE supervisor in shipyard

(including persons responsible for judging results)
b. Dependence of subcontracted NDE work: number of shipyard employees and subcontractors
c. NDE sub-contractor company's name and official technical qualifications
d. Grade and number of NDE employees with official technical qualifications in shipyard: specialized in radiography, ultrasonic and/or surface detection
e. If non-destructive examinations are subcontracted, the grade and number of officially qualified persons: specialized in radiography, ultrasonic and/or surface detection
f. Non-destructive examination equipment (in house): number of radiographic and ultrasonic equipment.

7. Quality control on Production Line
a. Preventative measures for misuse of materials
b. Shot blasting / Primer coating
c. Marking and cutting (Assembly work)
d. Bending and strain free
e. Control of welding procedure
f. Treatment of serious non-conformities
i. Repair plans submitted when serious non-conformities happens.
ii. NDE (Radiographic Test /Ultrasonic Test) plans submitted at appropriate time
iii. Test extension considering the result of test
g. Hydrostatic and watertight test
i. Test Plan submission
ii. Vacuum test and local air injection test during sub-assembly works (if applicable)

Kick off Meeting

Once the scope of work is defined, and shipyard facilities are known by BV, discussions with the shipbuilder regarding specific activities are crucial before commencing the construction. The Kick-off meeting is divided into two parts: general aspects and hull construction. To prepare and agree on activities during the construction, each item mentioned below is to be discussed, including description, agreement, remark/conclusion, follow-up, and due dates, as far as applicable.

General aspects contain:
• Description as per Classification Request
a. Class symbols and construction marks (which define the scope of the work to be performed from BV for drawing review and inspections at yard)
b. Service notations and navigation notations
c. Additional service features
d. Additional class notations
e. Statutory surveys as per agreed in RFC within the scope of the required certificates (verification of flag authorization/delegation, if applicable)
f. Other surveys for issuance of the specific attestations

• Description or detail of agreements between shipyard and BV
g. Applicable rules: BV rules, statutory/flag rules (to be available at the Shipyard)
h. List of drawings and documents to be submitted
i. List of materials and equipment to be certified
j. Statutory materials and equipment to be certified
k. Review of the construction facilities. (if update need to be done)
l. List of subcontractors with contacts to be provided by the Builder (design, hull construction, NDT, machinery, electricity, etc.)
m. Shipyard main contacts for BV Team
n. Circulation and distribution of drawings/ documents between Builder/ Shipyard and BV
o. BV intervention procedure to be applied: Intervention form, notification time, shipyard inspections prior to BV survey, safety conditions during surveys
p. Inspection plan (witness and notified points, etc.) to be submitted by the Builder to BV
q. Unscheduled or patrol inspections (BV may perform patrol inspections at any time during the construction, plan and access to be agreed with Shipyard)

r. Process to issue and clear non-conformities on reviewed drawings and result of inspections
s. Shipyard fabrication standard to be accepted by BV
t. Quality meetings with the Builder/ Shipyard when deemed necessary. Subjects such as (but not limited to): additional survey, missing drawings or certificates, pending remarks, etc. Minutes of meeting to be recorded and followed-up
u. Documents given to the Builder during the KoM: any documents deemed necessary, such as (but not limited to): list of drawings and materials to be certified, Approval Testing of Welders, etc.
v. Documents requested from the Builder during the KoM, such as (but not limited to): block plan, inspection plan, NDT plan and reports, WPS and WPQR, tank test list, software registry, cable transit seal systems register, ship construction file.
w. Documents requested from the Builder before ship delivery , such as (but not limited to): commissioning and test records , dock trial records , sea trial records
x. Documents issued to the Builder/Client at ship delivery , such as (but not limited to): class and statutory certificates , attestations
y. Plan Approval office
z. Miscellaneous as PSPC, Asbestos attestation, Steering gear test, Tank test plan, Green passport, Ship Construction File, Others

The second part contains specific activities of the hull construction survey. The purpose is to discuss in detail with the Shipyard QA-QC team, requirements and the principle of Patrol surveys performance. Each item mentioned below need to be discussed including survey requirement and survey method, BV rules, statutory requirements (if any), relevant references, documentation available to the surveyor during the construction, documentation for the ship construction file, specific activities and BV proposals for the project as far as applicable.

- Shipbuilding quality control

a. Welding (welding consumables, welder qualification, welding procedures, welding equipment, welding environment, welding supervision, welding surface discontinuities, welding embedded discontinuities)
b. Steel preparation and fit-up (surface, preparation marking & cutting, straightening, forming, conformity with alignment/fit-up/ gap criteria, conforming for critical areas with alignment / fit-up or weld configuration
c. Steelwork process (e.g. sub assembly, block, grand and mega block assembly, pre-erection and erection, closing plates)
d. Remedial work and alteration
e. Tightness testing, including leak and hose testing, hydro pneumatic testing
f. Structural testing
g. Corrosion protection systems (e.g. coatings, cathodic protection, impressed current except for coating system subject to PSPC), application antifouling systems, application of protective coating for dedicated seawater ballast tanks.
h. Installation, welding and testing for hatch covers, doors and ramps integral with the shell and bulkheads, rudders, forging and casting, appendages, equipment forming the watertight and weathertight integrity of the ship (e.g. overboard discharges, air pipes, ventilators), freeboard marks and draft marks, safety construction certification, watertight cable transit systems.

Result During Construction Process Using BV It Tool

The project is created in a BV IT Tool called Veristar Project Management (VPM). This tool is utilized throughout the entire construction process and is accessible to internal and external stakeholders such as shipyards, designers, product suppliers, and the owner, as long as it is permitted by the client.

The purpose of the tool is to assist with the management of the project throughout every activity required for construction until delivery. This tool has been developed in compliance with the BV Quality system, design approval, and established new construction procedures.

All VPM users are provided with general information about the project, stakeholders, the follow-up of plan approval assessments, the follow-up of equipment and material certification processes, the follow-up of construction surveys, submission of drawings, and the option to reply online to comments issued during the plan approval process or construction survey, as illustrated in Fig. 2.

The tool it is divided in four main parts:

- Definition of the contract 'Project data'
- Validation of the design ' Design review' managed by Plan Approval surveyors
- Equipment & material certification ' Product certification' managed by BVN surveyors
- Survey of Construction ' Survey at shipbuilder' managed by Surveyors at Yard

Plan approval office(s) initiate drawing/documentation review of the ship itself but also to the specific equipment. As result two type of comments can be created:

- Type 'to be resubmitted' is to be cleared by design office/shipyard. It can be created for request of new revision, supporting documentation or calculation required.
- Type 'to dealt with' is to be cleared by Surveyor at Yard. It is created to perform inspection on board which ensure compliment of a specific requirement.

Additionally, some parallel projects are created in the same VPM tool based on material and equipment certifications as identified at the Kick-off Meeting (KoM). These projects are linked to the main ship project to provide a complete overview of the certification process. The tool allows users to see the status of the process and whether any comments need to be addressed by plan approval surveyors, BVN surveyors, yard surveyors, or from the client side.

Regarding inspections at the yard, a tree is created in VPM based on the marks and notations defined, and data input available in the system at the signature of Classification Request. It can be modified if needed based on the complexity of the project or other factors. This tree lists every scheduled and unscheduled item to be inspected, trials to be performed, and quality documentation to be recorded.

VPM includes different spaces to maintain traceability of the main items to be monitored, verified, validated, witnessed, inspected and tested as far as agreed during the pre-project process at KoM. Moreover, VPM inform BV NC Team when quality documentation is missing prior to specific milestone dates. Missing documentation may be linked but not limited to shipyard review record, Kick off meeting, welding procedures specification, welding qualifications, NDT records, patrol plan agreed, sea/river quay trials procedure, reminders to client about pending comments, etc.

Prior to delivery of the project, two last process are performed by the BV Project Leader and validated

Fig. 2. Workflow during design and construction phase using VPM.

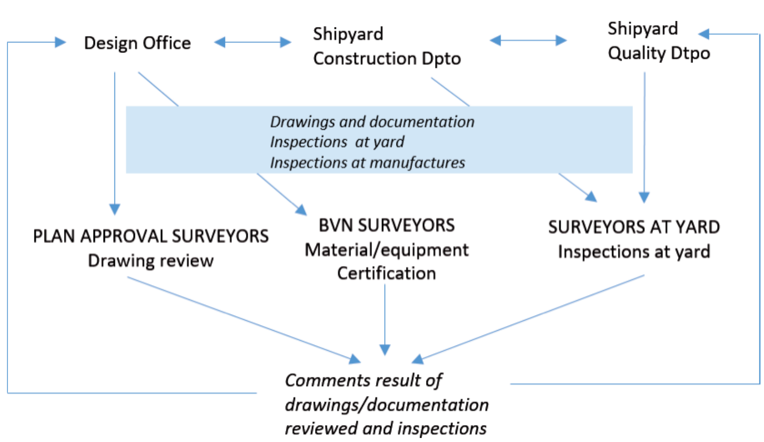
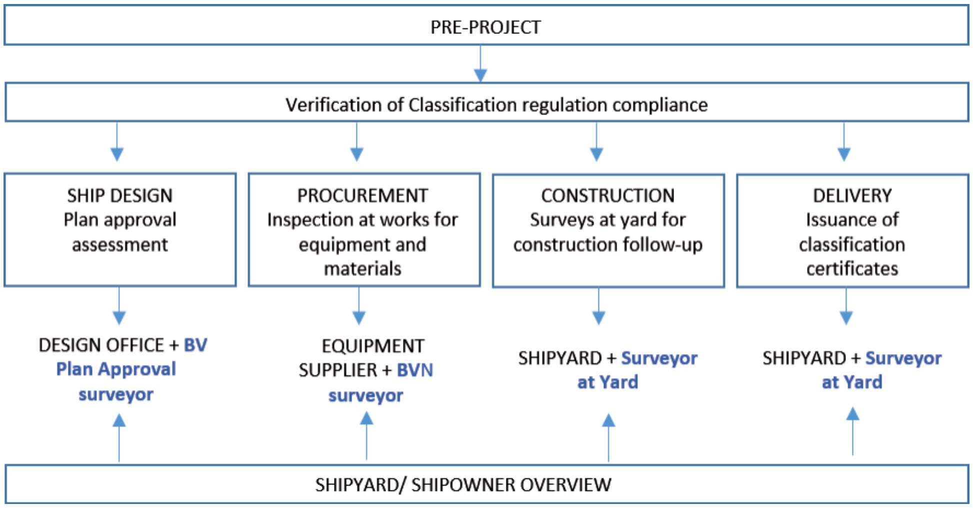


Fig. 3. Involvement of stakeholders during entire construction process.



by the new Construction local manager. Process consist to review that all required drawings have been received and reviewed, all material and equipment certificates are received, all quality documentation is received and none pending comments.

In case of outstanding point remains, agreed solution between client and BV is to be specified. Such process allow to go through the following phase, Issuance of Classification Certificate.

With proper recommendation or memoranda (if applicable) in accordance with those agreement indicated during the first phase.

References

1. Ionel Danul SAVU, New concept of quality management in shipbuilding. Advanced Engineering Forum Vol 13, pp 332-340 (2015)

2. IACS Homepage, Unified requirements URZ23 Rev 7. https://iacs.org.uk, last accessed 2022/11/20.

3. Bureau Veritas, Internal Procedures for New Construction Building Version 3.12 (April 2022)

4. Abdulaziz A Bubshait, ISO 9000 Quality standards in Construction. Journal of Management in Engineering (1999)

Challenges in the systems integration process in naval units. Case study: Data Distribution Unit Project

Desafíos en el proceso de integración de sistemas en unidades navales. Caso de estudio: Proyecto Unidad de Distribución de Datos

DOI: https://doi.org/10.25043/19098642.246

Francisco Guevara [1]
Ronald López [2]
Willy Ramos [3]
Sergio Mendoza [4]
Stefany Marrugo [5]

Abstract

This article presents the challenges faced by the Research and Development Department of COTECMAR in the process of systems integration in naval units. For this purpose, it is used as a case study, the project through which a Data Distribution Unit (DDU) designed for ships of the Colombian Navy was developed and implemented. The methodology implemented for the development of the DDU is shown in summary form, with special emphasis on the implementation and testing phase; likewise, the main drawbacks identified and the most relevant lessons learned related to the integration of hardware and software modules that make up the DDU are presented. In this sense, it was found that in about 30% of the cases, the novelties or difficulties that arose, especially in the software implementations, were due to inaccurate information from the original manufacturers' manuals and undocumented updates. Finally, recommendations are made to improve onboard systems integration processes.
Key words: Data Distribution Unit (DDU), systems integration, naval systems.

Resumen

Este artículo presenta los desafíos que enfrenta el Departamento de Investigación y Desarrollo de COTECMAR en el proceso de integración de sistemas en unidades navales. Para ello, se emplea como caso de estudio, el proyecto mediante el cual se desarrolló e implementó una Unidad de Distribución de Datos (DDU) diseñada para buques de la Armada de Colombia. Se muestra de forma resumida la metodología implementada para el desarrollo de la DDU, haciendo especial énfasis en la fase de implementación y pruebas; así mismo, se presentan los principales inconvenientes identificados y las lecciones aprendidas más relevantes, relacionadas con la integración de los módulos de hardware y software que componen la DDU. En este sentido, se encontró que en alrededor del 30% de los casos, las novedades o dificultades que se presentaron, especialmente en las implementaciones de software, obedecieron a información imprecisa de manuales de los fabricantes originales y actualizaciones no documentadas. Finalmente, se emiten recomendaciones orientadas a mejorar los procesos de integración de sistemas a bordo.
Palabras claves: Unidad de Distribución de Datos (DDU), Integración de sistemas, sistemas navales.

Date Received: October 29th, 2022 - *Fecha de recepción: 29 de octubre de 2022*
Date Accepted: February 16th, 2023 - *Fecha de aceptación: 16 de febrero de 2023*

[1] R&D Department - COTECMAR. Email: fguevara@cotecmar.com
[2] R&D Department - COTECMAR. Email: rlopez@cotecmar.com
[3] R&D Department - COTECMAR. Email: wrramos@cotecmar.com
[4] R&D Department - COTECMAR. Email: smendoza@cotecmar.com
[4] R&D Department - COTECMAR. Email: smarrugo@cotecmar.com

Introduction

The frigate type units of the Colombian Navy's Almirante Padilla class have a Data Distribution Unit (DDU), whose function is to concentrate and integrate the signals obtained from the ship's navigation sensors and, subsequently, distribute them to other sensors and systems that require them for the fulfillment of their mission.

The "Data Distribution Unit" (DDU) that these units currently have was developed during the execution of the modernization process of the Almirante Padilla class frigates Plan ORION (between 2009 - 2011), in order to replace the old and obsolete navigation data retransmission module, known as RTU, which was in charge of receiving and retransmitting the analog signals from the navigation systems to the ship's equipment and systems that required them. With the change in technology from analog to digital, both in the sensors that produce/generate the information and in the equipment or systems that consume or require that information, the need to replace the previous system materialized [1].

The DDU allows centralizing the input signals from the navigation sensors, managing the distribution of the original data from each sensor, monitoring the input data and providing multiple outputs, in different serial and analog formats, proprietary or standard for the different equipment or systems that require such navigation data for their operation [1]. Similarly, the DDU is designed to be redundant, in terms of data availability of different variables and the operation of its internal components. Consequently, the main critical elements of the system include backup capability [2].

COTECMAR, as a Science and Technology Corporation, in its role of contributing to the development of capabilities for the Colombian Navy, led the execution of a research project in the field of systems integration in naval units, consisting of the development of a Data Distribution Unit (DDU) prototype; this project represented an important technological and technical challenge, which allowed strengthening capabilities and acquiring knowledge, which is reflected in a functional DDU prototype that was tested in the laboratory and on board an Almirante Padilla Class frigate.

This paper presents the development process carried out by COTECMAR to obtain a functional DDU prototype and the main challenges faced during the execution of projects of this nature on board naval units.

Solution design

The main objective of the Prototype of a Data Distribution Unit (DDU) for the Frigate type units of the Admiral Padilla class of the Colombian Navy was to integrate the data from the ship's navigation sensors for its distribution to the navigation, surveillance, command and control and/or armament equipment/systems that require it. Such objective would be achieved by receiving the information delivered by the unit's sensors, its management/storage and subsequent distribution [3]. From the system requirements analysis, the DDU Prototype requires the following main hardware components:

- Processing units: responsible for the execution of all the system's software modules, which process the data received from the sensors (Navigation Data Producers - NDP's), generate the data frames required by the equipment/consumer systems (Navigation Data Consumers - NDC's) and execute the additional system control tasks. The prototype was designed with two processing units to ensure redundancy in the operation of the system.
- Physical interfaces: Set of components whose function is to connect to the data output ports of the sensors and deliver the data frames to the processing units, ensuring that each unit receives the same information from the sensors. They must also perform the reverse process and connect to the data input ports of the consuming equipment/systems and deliver the required information. These components must perform the conversion of the signals received

from the physical ports of the sensors, so that they can be read by the interface peripherals of the processing units.
- Network connection: Allows interconnecting in a data network the different components of the system, such as the processing units, the data display unit, the physical interfaces, among others.
- Data visualization: Component that allows displaying the Graphic Interface or HMI of the system, for interaction with the operator through visualization and operation tasks.
- Power supply: Set of equipment and accessories whose function is to supply the power required by the different components of the system. For the design, redundancy in the power supply components is considered [4].

Regarding the software components required for the implementation of the prototype, the main modules are described below:

- Interfaces: It is the software module in charge of receiving information from the navigation sensors from the external interfaces and, subsequently, sending such information to the equipment/systems that require it. It is composed of the following sub-modules: Interface for receiving data from the ship's navigation sensors (IF Rx), Interface for transmitting navigation data to the systems/ equipment that require it in the established format and/or protocol (IF Tx).
- Processing: This is the software module in charge of storing and organizing the information obtained from the sensors. It is composed of the following sub-modules: Coordinator (in charge of supervising the execution and initialization of the different modules and/or software sub-modules), Supervisor (in charge of controlling the data manager, to guarantee the operation of the system according to the operation mode selected by the operator) and Data Manager (in charge of keeping the navigation information received from the ship's sensors dynamically stored, for its later distribution to the receiving equipment).
- HMI: It is the human-machine interface software module, where the operator will be able to visualize the navigation data values, manage the system configurations and monitor and control the system. It is composed of a presentation submodule (in charge of displaying the information received from the ship's sensors and the system status) and another one for configuration/control (its function is to interact with the operator to establish the configurations of the operation modes to be used).
- Messaging: The means by which different software modules (and sub-modules) can exchange information with each other [6].
- Security: This module is transversal to those described above, and includes aspects ranging from the management of network switch ports, through frame validation mechanisms, to the application of functionalities in the HMI to generate user profiles and protect the level of access that an operator would have to the system.

Fig. 1 shows the general software architecture for the DDU Prototype, including the modules and sub-modules described.

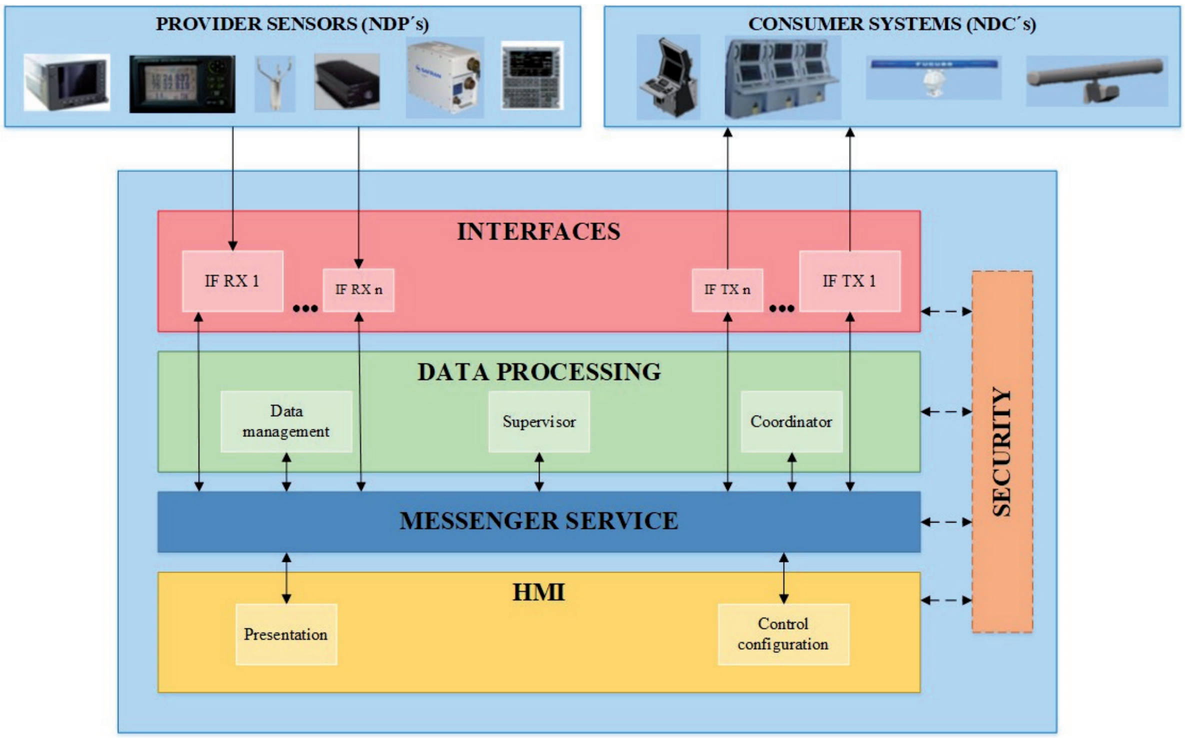
Implementation and testing

The implementation of the design foreseen for the DDU prototype implied the development of several technical information gathering activities on board the ARC Almirante Padilla class frigates. The technical staff of the weapons and electronics department of the ARC Bolivar Naval Base and the support of the units' crews assisted in this process.

As a result of the surveys and review of manuals, 16 links were identified between the existing DDU and its navigation data producers/consumers. These can be derived in sub-links, depending on the equipment that is connected. Likewise, some of the integrated signals are high frequency, so they will require specialized hardware for their processing.

On the other hand, the supply of hardware required for the implementation of the DDU prototype

Fig. 1. General software architecture for the DDU prototype [7].



developed by COTECMAR, is composed, among other equipment and accessories, by the following items:

- Processors.
- Human-Machine Interfaces.
- Devices for input/output signal management.
- Serial data servers.
- Environmental monitoring modules.
- UPS sources.
- AC and DC power distribution units.
- Ventilation modules.
- Standard 19' rack.
- Wiring, connectors and pins between equipment for internal and external interfaces (in laboratory).

Fig. 2 presents the front view of the implemented DDU prototype. In the image, the different hardware modules described in section 2 can be identified.

With a view to validate the software and hardware developments of the DDU prototype, a testing protocol was executed, which took place in the laboratory of the R&D department of COTECMAR. The test protocol was divided into test cases [8], as follows:

- Test case 1. Visual inspection of components. In this section the hardware components of the prototype were validated, verifying quantities, references, manufacturers, part numbers and the identification numbers assigned in the design process to each component. Likewise, the wiring of the connection interfaces between the components was validated.
- Test case 2. Start-up of the DDU. This test allowed validating the start-up process and correct initialization of all DDU components.
- Test case 3. Backup power supply and UPS. In this test, all actions aimed at validating the correct operation of the redundancy in the power supply of the system were carried out. Likewise, tests were carried out to verify the operation of the prototype using only the UPS as power supply.
- Test case 4. HMI functionalities. This test allowed verifying the deployment of the human machine interface, according to the required

functionalities for each case. It was validated that the different views and tabs of the HMI allowed visualizing the information coming from the sensors. Fig. 3 shows a screenshot of the summary tab of the HMI developed by COTECMAR for the DDU prototype.

Fig. 2. Functional DDU prototype - laboratory test configuration.

- Test case 5. NDPs (Navigation Data Producers) data integration. This test allowed validating that the simulated information coming from the different onboard systems and sensors, which act as navigation data producers or providers, was effectively being managed in the processing units and could be displayed in the DDU's HMI, for its subsequent sending to the consuming systems. To run this test, the use of the NemaStudio signal simulator and the program developed by COTECMAR to reproduce sensor frames taken from onboard the units were required.
- Test case 6. NDCs (Navigation Data Consumers) data integration. In this section the information coming from the NDPs was validated to be available in the outputs that would be connected to the navigation data consumers. Additionally, with the execution of this test, the redundancy of the DDU data processing units was validated, based on the interruption of data sending by one of the processors and verification that the NDCs were receiving the relevant data. To perform this test the use again the Nema Studio simulator, the frame player developed by COTECMAR and an application for serial data capture running on a computer simulating a navigation data receiver were necessary.
- Test case 7. Integration of own and

Fig. 3. DDU HMI Summary tab [9].

Fig. 4. NemaStudio simulator - example of GPS configuration[10].

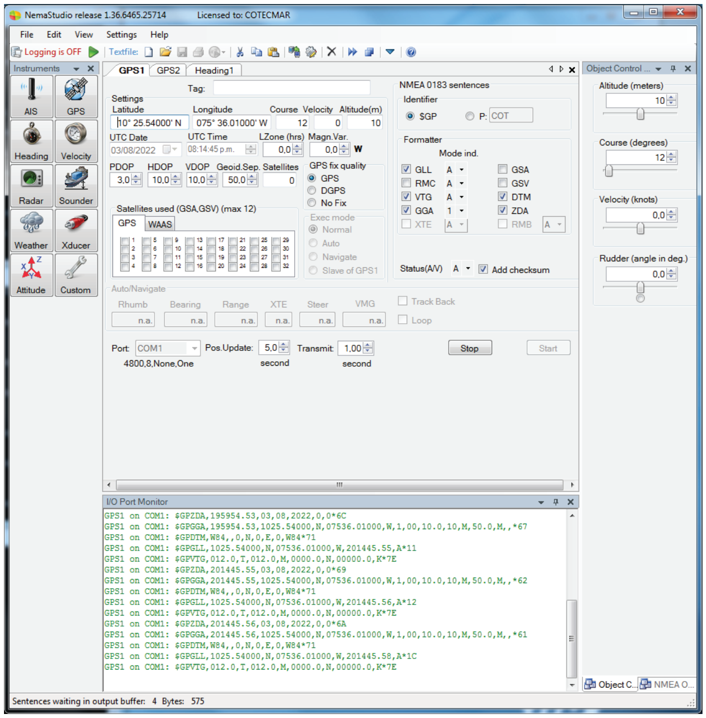
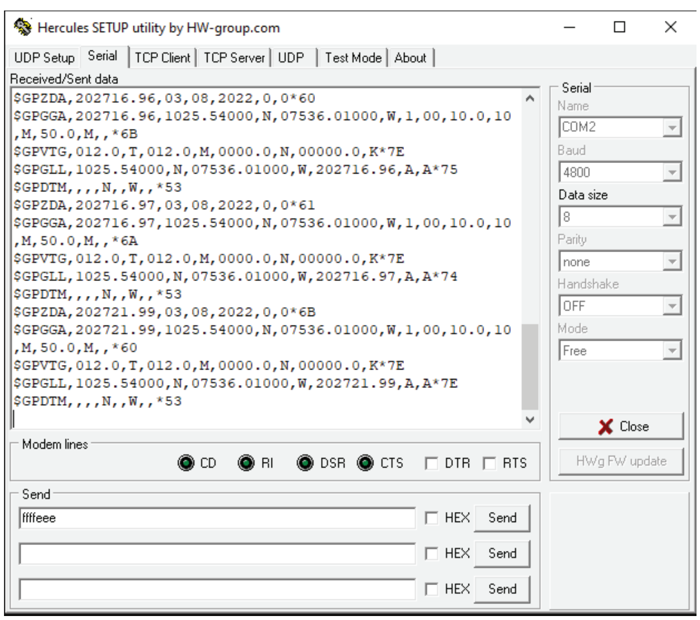


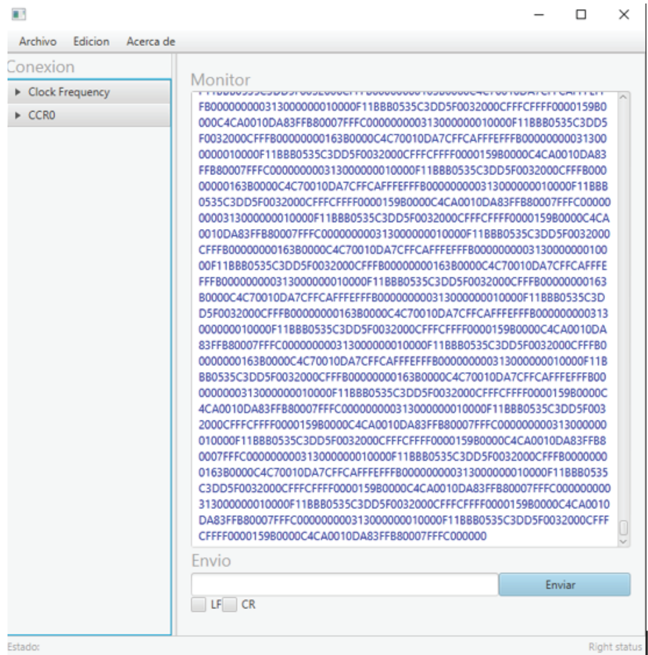
Fig. 5. Serial data reading application [11].



stabilization data. This test allowed validating the frames that are processed and generated by the DDU prototype, from the information coming from the sensors and NDP systems, which is required by the ship's weapon system.

For the execution of this test, in addition to having the applications described in test case 6, it was necessary to have the FASTCOM HDLC frame application (developed by COTECMAR) in a computer.

Fig. 6. Byte stream - HDLC frame monitor [12].



The execution of the described test cases had a duration of one (01) day, under controlled temperature and environment conditions, as follows:

- Ambient temperature: below 25°C.
- Available power supplies: main 115VAC/50Hz; backup (simulated) 24VDC.
- NDPs simulator: Gyrocompass, GPS, Echo sounder, Weather station, AIS, logger.
- There are two (02) data outputs for each simulated input sensor.

It is important to highlight that the test protocol described was 100% completed, successfully fulfilling the objective of the research project. The validation of the results was carried out by personnel of the Colombian Navy, belonging to one of the Almirante Padilla class frigates.

Considering the results obtained in the laboratory tests, the Colombian Navy requested to execute tests of the DDU prototype on board a Frigate. This implied making some adjustments to the hardware and software modules of the system, to adapt them to the operational environment on board; this process lasted approximately four (04) months. In general terms, the ARC personnel of the Frigate expressed their acceptance towards the prototype developed thanks to the successful integration of the navigation and combat systems on board. Although there were some novelties and opportunities for improvement during the test period, all of them were addressed and solved in a timely manner by COTECMAR.

Fig. 7 shows the prototype DDU developed by COTECMAR installed (provisionally) on board a frigate for testing in a real operating environment.

Main challenges

The development process of the DDU prototype involved the analysis and solution of some situations that materialized and that, in some way, became challenges that had to be solved and managed to achieve the successful execution of the project.

Tables 1 and 2 describe some of the situations identified, classifying them according to whether they applied to hardware or software modules.

Table 1. Challenges - hardware modules.

Factor or Requirement	Description Situation	Solution
Card redundancy for onboard digital and analog signals.	The cards used in the on-board DDU were a custom solution made by a manufacturer. They are not available commercially.	Detailed study and analysis of the logic required for the solution and subsequent design/development of the cards to guarantee signal redundancy.
High-speed signals	It was necessary to integrate high speed signals (250,000bps) and the tools required to acquire this information on board were not available for the laboratory testing process of the prototype.	Identification, acquisition, and configuration of specific hardware to be able to extract the information required for the execution of tests. It is important to highlight that the acquisition of this hardware had a high cost associated with it.
Pinout documentation	Basic technical documentation. There was insufficient detail on the physical integration of some of the existing DDU modules. This delayed the onboard signal integration process.	Field analysis of the signals and internal pinouts of cards, to build a detailed documentation of the developed prototype.
Laboratory test signals	The *synchro* signal in analog format could not be validated in the laboratory, due to the lack of 115VAC 400Hz signal generators.	This signal was tested on board a Colombian Navy frigate.
On-board test execution times	Long power-on (and stabilization) times were required for sensors and on-board systems, which altered the planned work schedule for test execution.	Schedule management, based on adjustments to the test schedule and joint work with the ship's personnel for effective coordination prior to the execution of the tests.
Procurement of components	Delays in the logistical process of acquiring hardware components required for project execution, as an indirect consequence of the pandemic. Prolonged manufacturing lead times for specialized components.	Schedule management. Contact with suppliers to agree on dates adjusted to the requirements and execution of parallel design and information gathering activities to avoid delays in the project master schedule.
Signal multiplexing	During the execution of tests on board the Frigate, problems were being generated in the transmission of input information to the DDU prototype developed by COTECMAR.	A detailed case analysis was performed. The input signals (from onboard sensors/systems) were separated and grouped according to their data rates.

Fig. 7. Functional DDU prototype-testing aboard a frigate.

Conclusions

The application of the existing knowledge and capabilities in the R&D department of COTECMAR, allowed the development of a functional prototype of a Data Distribution Unit - DDU, adjusted to the requirements of the Almirante Padilla class frigates of the Colombian Navy. In this sense, the functional validation of the development was done both in the laboratory and in a real operational environment (on board a frigate), obtaining successful results in both cases.

Likewise, this project allowed the appropriation of new knowledge and capabilities related to systems and sensors integration, especially regarding the management of onboard analog signals and their respective digitalization.

Likewise, based on the technical challenges and difficulties encountered during the prototype

Table 2. Challenges - software modules.

Factor or Requirement	Description Situation	Solution
Synchro documentation	There was no documentation describing the exact data that made up the output frame of this signal.	Field tests were carried out to analytically identify the necessary treatment of the data to generate the signal.
Missile system data documentation	Poorly detailed documentation of the processing of data going to the SS missile system.	Field tests were carried out to analytically identify the necessary treatment of the data to generate the signal.
HMI design	An HMI design was required that could group and represent the data of interest to the DDU operator, considering ergonomics and information prioritization criteria, which would also allow monitoring the information managed by the DDU in real time.	Several preliminary HMI designs were made and socialized at worktables with operators of the existing DDU in the ARC units, to have adequate feedback for the selection. Additionally, adjustments were made to the form (color, font sizes, decimal display, etc.) of the HMI during the prototype testing phases.
HMI development components	Once the graphic design of the HMI was selected, we worked on a version based on a tool that had a high RAM memory consumption, which caused the application to crash.	Identification and selection of components that would make a good treatment of RAM consumption and that would not imply the reduction of interface display capabilities.

development process, the following conclusions or lessons learned are generated, as follows:

- Around 30% of the problems that arose, both in hardware and software, were due to basic or outdated technical documentation, which meant that the technical personnel working on the project had to increase their dedication to field data collection and analysis activities to fill the information gaps.
- It is important to validate the designs with the end user or operator prior to the implementation phase of the projects. In this case, the validation of the HMI design with the onboard operators allowed to adjust and direct the interface development efforts in a timely manner, so that it would be functional and intuitive.
- The proper management of the schedule of a project of this nature, as well as the timely identification and mitigation of the risks detected, allow the efficient completion of objectives. In this case, we tried to parallelize hardware/software design and development activities with the logistic delivery times of the components required for the implementation of the prototype. This allowed mitigating delays in the project's macro schedule.

Recomendations

- Assign sufficient time to the process of selection and analysis of hardware component characteristics, so that the materials and equipment to be acquired fully meet the expected requirements.
- Ensure that the required components and tools are available to perform the laboratory validation tests of the advances.
- Continuously train the technical personnel involved in the execution of this type of projects, with a view to enhancing system and sensor integration capabilities.
- Maintain a continuous feedback process with the client or end user, to identify new requirements and guide future work.

Acknowledgments

The authors would like to thank the crews of the frigates of the Colombian Navy for their support in the development and testing process of this project, as well as the personnel of the Weapons and Electronics Department of BNL01 for their support in the design and validation process of the prototype.

References

[1] COTECMAR. System Requirements Specification - DDU Prototype, pp. 8-9. Available at COTECMAR COT 2101 - DDU PROJECT DOCUMENTS. Accessed 2022-10-26.

[2] COTECMAR. System Requirements Specification - DDU Prototype, pp. 22-23. Available at COTECMAR COT 2101 - DDU PROJECT DOCUMENTS. Accessed 2022-10-28.

[3] COTECMAR. System Design - DDU Prototype, pp. 11. Available at COT 2101 - DDU PROJECT DOCUMENTS. Accessed 2022-11-18.

[4] COTECMAR. System Design - DDU Prototype, pp. 13-16. Available at COTECMAR COT 2101 - DDU PROJECT PROJECT DOCUMENTS. Accessed 2022-11-24.

[5] COTECMAR. System Design - DDU Prototype, pp. 23. Available at COT 2101 - DDU PROJECT DOCUMENTS. Accessed 2022-11-27.

[6] COTECMAR. System Design - DDU Prototype, pp. 17-20. Available at COTECMAR COT 2101 - DDU PROJECT DOCUMENTS DISI. Accessed 2022-11-26.

[7] COTECMAR. System Design - DDU Prototype, pp. 25. Available at COT 2101 - DDU PROJECT DOCUMENTS. Accessed 2022-11-27.

[8] COTECMAR. Factory test protocol - DDU prototype, pp. 15-40. Available at: \\COT 2101 PROJECT - DDU Technical Documents. Accessed on 2022-12-22.

[9] COTECMAR. Factory test protocol - Prototype DDU, pp. 62. Available at: \\COT 2101 - DDU Technical Documents - DDU Technical Documents. Accessed on 2022-12-23.

[10] COTECMAR. Factory test protocol - DDU prototype, pp. 71. Available at: \\COT 2101 - DDU Technical Documents - DDU Technical Documents. Accessed on 2022-12-23.

[11] COTECMAR. Factory test protocol - Prototype DDU, pp. 100. Available at: \\COT 2101 PROJECT - DDU Technical Documents. Accessed on 2022-12-23.

[12] COTECMAR. Factory test protocol - DDU prototype, pp. 106. Available at: \\COT 2101 - DDU Technical Documents - FAT. Accessed on 2022-12-23.

Perspectives for the development of unmanned surface vehicles in Colombia: COTECMAR case

Perspectivas para el desarrollo de vehículos de superficie no tripulados en Colombia: El caso de COTECMAR

DOI: https://doi.org/ 10.25043/19098642.247

Daniel Mauricio Cubides Garzón [1]
Adriana Milena Castaño Padilla [2]
Hernán David Vergara Pestaña [3]

Abstract

The fourth industrial revolution began a few years ago with the advancement and integration of artificial intelligence, digitalization, and automation in different economic sectors. The naval industry in different countries has also been at the forefront of this revolution, introducing robotics to achieve ships with levels of automation and surface vehicles with autonomous navigation, which can operate without crew on board. This is how the Colombian naval industry has also started this path towards maturity in the development and integration of 4.0 technologies in unmanned surface vehicles (USV), being pointed out in the naval development plan 2042 [1] of the Colombian Navy as an opportunity for technological advancement. COTECMAR, being a fundamental part in the support and projection of the Colombian Navy's capabilities, proposes a route for the design and construction of the first Colombian USV; for this reason, this article presents through a review, the efforts and progress made in the past and to date, as well as what is proposed for the future, the challenges and impact on the Colombian naval industry. This review will allow the generation of a strategic vision in the current members of the project and may also generate new interested parties that, through their knowledge, will generate valuable contributions that can promote a project that will guide the Colombian Navy towards the technological vanguard.

Key words: USV, Industry 4.0, Autonomous.

Resumen

La cuarta revolución industrial comenzó hace unos años con el avance e integración de la inteligencia artificial, la digitalización y la automatización en diferentes sectores económicos. La industria naval en diferentes países también ha estado a la vanguardia de esta revolución, introduciendo la robótica para lograr barcos con niveles de automatización y vehículos de superficie con navegación autónoma, que pueden operar sin tripulación a bordo. Así es como la industria naval colombiana también ha iniciado este camino hacia la madurez en el desarrollo e integración de tecnologías 4.0 en vehículos de superficie no tripulados (USV), siendo señalado en el plan de desarrollo naval 2042 [1] de la Armada Colombiana como una oportunidad para el avance tecnológico. COTECMAR, siendo una parte fundamental en el apoyo y proyección de las capacidades de la Armada Colombiana, propone una ruta para el diseño y construcción del primer USV colombiano; por esta razón, este artículo presenta a través de una revisión, los esfuerzos y avances realizados en el pasado y hasta la fecha, así como lo que se propone para el futuro, los desafíos e impacto en la industria naval colombiana. Esta revisión permitirá la generación de una visión estratégica en los actuales miembros del proyecto y también puede generar nuevos interesados que, a través de sus conocimientos, generarán valiosas contribuciones que pueden promover un proyecto que guiará a la Armada Colombiana hacia la vanguardia tecnológica.

Palabras claves: USV, Industria 4.0, Autónomo.

Date Received: November 3rd, 2022 - *Fecha de recepción: 3 de noviembre de 2022*
Date Accepted: February 20th, 2023 - *Fecha de aceptación: 20 de febrero de 2023*

[1] Gerencia de Diseño e Ingeniería de COTECMAR. Cartagena, Colombia. Email: dcubides@cotecmar.com
[2] Gerencia de Diseño e Ingeniería de COTECMAR. Cartagena, Colombia. Email: amcastano@cotecmar.com
[3] Gerencia de Diseño e Ingeniería de COTECMAR. Cartagena, Colombia. Email: hdvergara@cotecmar.com

Introduction

This is how each of the stages in which there has been a peak in science and technological inventions has represented a revolution, from the invention of the steam engine to the technological revolution, three industrial revolutions are considered. Today with the rise of artificial intelligence, digitization and automation, a fourth industrial revolution or Industry 4.0 is mentioned. which is mainly based on the ability to integrate systems, which combines physical infrastructure with software, sensors, digital and communications technology [2].

These advances that identify Industry 4.0 have also had an impact on the maritime, riverine and naval sector, being applied in the development of autonomous manned and unmanned vessels, in which communication systems, cybersecurity, digital and industrial identity, artificial intelligence, virtual reality, distributed data base, among others, are integrated.

The development of USV has been welcomed mainly by the naval sector, with the aim of using this type of technology to support naval vessels in missions that may pose a threat to the crew, such as mine sweeping, armed escort, anti-piracy, surface warfare, among others, and thus reduce risks to life.

Likewise, this article brings together the efforts that have been made in Colombia around the USV subject, in which COTECMAR as a support shipyard of the Colombian Navy seeks to strengthen its capabilities to integrate and develop existing technologies in the framework of Industry 4.0 that allow progress in the development of ships with autonomous levels and [3] unmanned surface vehicles.

Background

The Colombian Navy, in the Force Planning document to 2042, states the need to build multi-mission frigate type ships in the Strategic Surface Platform Program (PES) [1], which will have means to support the defined missions in which USVs are contemplated. Thus, COTECMAR, in line with its strategic direction, has allocated resources to address the issue of autonomous and unmanned vehicles [3]. The efforts made are shown below.

USV SÁBALO.

In 2000, during the process of updating, modernizing, repowering and extending the useful life of the FS-1500 frigates under the "Orion" plan, the Navy received an offset benefit from the Innova organization [4].

As a result of this benefit, it was agreed to execute the USV SÁBALO project, which would be focused on the development of missions in river environments. The missions were focused on: SOF (Special Operations Forces), surveillance, reconnaissance, patrolling and river control. For the development of these missions, the vehicle would have ISR (Intelligence, Surveillance and Reconnaissance) capabilities, through equipment such as: An IMU (Inertial Measurement Unit), GPS, Electronic Compass, AIS, EO/IR cameras and underwater sonar [5].

Despite the previous capabilities, the USV SÁBALO did not have the possibility of being improved or used, the system is considered as a “black box” [6], and the Colombian Navy could not use it in operational environments with the capabilities with which it was designed for, instead it was used for research and development of research project within the Escuela Naval de Cadetes Almirante Padilla.

COTECMAR state of art.

In 2019 COTECMAR began with the development of a state of the art that would allow identifying the status and progress of unmanned surface vehicle technology. This study was consolidated through the publication of a chapter in a book called "Unmanned surface vehicles: technology advancement and its application in the Colombian Navy" [7].

The study allowed developing different points about USVs, the first one was a definition of unmanned surface vehicles according to different concepts, thus generating a definition on which the study would be carried out. This definition states the capability of the vehicles to perform tasks on the water surface, which will depend on their design, equipment, and configuration. Additionally, it is mentioned that it is usually thought that they have the capacity to operate without human presence in the vehicle, which may not be the case for those that have dual use, multiple use or simply human personnel in the vehicle performing some kind of tests or evaluation.

The state of the art also made it possible to generate an overview of aspects such as:

- The applications that these vehicles can have within the Colombian Navy.
- The missions and functions they currently perform.
- The centers and authors recognized for their studies in the field.
- The advantages of USVs
- The impacts that this technology can have on the National Navy.
- A summary of the main vehicles along with their characteristics, present in the world.

Regulations applicable to unmanned surface vehicles.

All current regulations on operation, assumption of responsibilities of shipowners, insurance, classification societies and the environment are regulated in the navigation and operation of vessels with crew on board, which is why it has become necessary to mention the legal scope for autonomous and unmanned vessels, as well as the responsibilities involved in the navigation of these, in case of maritime accidents, collisions, spills, sinkings, the responsibilities of the shipowner must be determined, defining the limit of operations and navigation.

Thus, in 2020, COTECMAR, together with other companies in the naval sector, such as Marine Colombiane, Navantia, Naval Group and CMN, participated in the review and contribution of comments to Bureu Veritas, a company that would be generating regulations and standards associated, among others, with autonomous and unmanned vehicles.

Through COTECMAR's participation, different chapters of the SOLAS convention and the MASS UK code of practice and principles of conduct for autonomous maritime vessels were analyzed and commented on, so that Bureau Veritas will integrate expert knowledge on the requirements of the regulations that are maturing. The documents or chapters reviewed by COTECMAR are as follows:

- MASS UK Industry Conduct Principles and Code of Practice 2019 (V3)
- SOLAS Chapter IV Radio communications
- SOLAS Chapter V Safety of navigation
- SOLAS Chapter VII Carriage of dangerous goods
- SOLAS Chapter XIV Safety measures for ships operating in polar waters

Fondo Caldas Project - Minciencias.

In the framework of the 2020 Minciencias call through Fondo Caldas, COTECMAR participated in the formulation and development of the project "Technology Demonstrator (TRL5) on the Unmanned Surface Vehicle for the frigate “Plataforma Estratégica de Superficie” (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". In this project COTECMAR participated in the integration of the USV control station, which delivers data to the Link-CO system, for the visualization of the USV telemetry in the tactical network through Link-CO's HMI.

USV prototype development – COTECMAR

COTECMAR as a science and technology corporation as well as a technological development center, has the capacity to develop innovative products for the Colombian Navy and external suppliers in Latin America. Therefore, the corporation has identified the opportunity to strengthen industrial and technological capabilities through the development of autonomous and unmanned vessels, which in the same way integrate the necessary equipment to develop the missions that the Colombian Navy defines in its functional requirements.

According to the Colombian Navy's Naval Development Plan (NDP) 2042, unmanned surface vehicles with military capabilities and scientific research present an opportunity for technological development and are part of the fourth industrial revolution, focused on the naval and maritime area [1].

The development of a USV must take into account its main components such as the following:

- Platform: Hull, propulsion and control system, power sources, electrical and auxiliary systems.
- Navigation and control: Sensors, navigation lights, software, sensing and monitoring equipment.
- Communication: Links between vehicle and remote monitoring and control station.
- Equipment and systems for mission: According to the mission for which the USV is designed, specific equipment is installed to develop it [8].

Taking into account what is mentioned in the NDP 2042 and the components of a USV, it is established that in order to achieve technological scaling, different routes for the development and production of autonomous and unmanned vehicle technology in COTECMAR are derived.

This initiative started from the Design and Engineering Management GEDIN, where goals are proposed to achieve this technological maturity. These initiatives began with the relationship with different expert companies in the design and construction of these vehicles, through the socialization of technical and commercial information, while it is presented as an opportunity to strengthen relations with a technological partner (strategic alliance), with which in the future they can serve potential customers of USV.

In the same sense, as an additional route to reach technological maturity, it is proposed to have a platform for the case study or a USV prototype that allows testing remote control of the vessel, as well as autonomous navigation. Both would be considered as the first achievements, prior to integration between equipment and sensors associated to the mission and the necessary components.

The design and construction of a prototype of an Unmanned Surface Vehicle is considered to have a technological maturity of TRL7 level, with the objective of testing in a real operating environment the basic missions of assisted and remotely controlled navigation.

Prototype mission.

USVs can perform different types of missions in the security and defense fields, according to the U.S. Department of the Navy, there are seven main missions [9]:

- Mine Countermeasures Warfare (MCM)
- Anti-Submarine Warfare (ASW)
- Intelligence, Surveillance and Reconnaissance (ISR)
- Maritime Security/Port Patrolling
- Surface Warfare (SUW)
- Special Forces Operations Support (SOF)
- Electronic Warfare (EW)
- Maritime Interdiction Operations Support (MIO)

According to the different missions described above, a mission associated with maritime and port security was selected for the USV prototype. This decision was made according to the availability of existing technology that can be included in the prototype for the proposed purposes, according to the scope of the project for this stage or maturity level initially outlined.

The main objectives of the mission will be:

- Patrolling and surveillance of the coverage area.
- Detection, tracking and target identification capabilities.

- Remote controlled navigation.

This is how the vehicle will be proposed to fulfill the mission of control and surveillance of coastal and port areas of the Bay of Cartagena and will operate in an area of approximately 4 *nmi*.

To test the prototype in the real operating environment, it is proposed to execute the basic mission described above and framed in the navigation area. Within this delimited area it will be possible to make the necessary communication links between the ground station and the vessel, a communication link will be established for the control and monitoring of the propulsion system, control, power supply and platform systems and another communication link for video transmission.

Unmanned navigation capability.

The USV prototype will have the capability to be operated by remote control, without onboard operating personnel. The prototype will also have the payload and software required to allow remote control of the platform and video supervision from the ground operation center.

USV General Specifications.

For the base platform of the USV prototype, the hull of the BRF shallow draft boat will be used for the integration of the systems, which is a hull of a vessel with military mission designed and tested by Cotecmar, with general characteristics that can be adjusted to the stability and maneuverability requirements of a USV, see Fig. 1.

The general characteristics of the platform established for the prototype are shown below:

- Length: 7 m
- Beam: 2.5 m
- Speed: 10 Kn
- Propulsion: 01 Electric FB Motor x 60 HP
- Battery autonomy: 1 hour
- Communication range: 1.5 km

The hardware and software for remote control of the vehicle will be based on the specifications of the electric outboard motor to be purchased.

Likewise, according to the USV's mission, sensors and basic equipment will be integrated for the satisfactory fulfillment of this mission (Cameras,

Fig. 1. Rendering of the USV prototype concept, based on the BRF hull.

navigation lights, antennas, radar, satellite compass, among others), which will allow the visualization of the environment and general situational awareness for decision making from the ground station.

The communications to be specified and installed on board the prototype will consider the amount of information and data to be transmitted between the vehicle and the ground control station, as well as the coverage area in which to test its performance and operation.

Future Work.

In the first scope for the USV prototype, efforts have been directed towards the preparation of the platform with its systems and the necessary equipment for the remote control operation mode as the first level of automation, stages 1 and 2 of the proposed route for the in-house development and maturity of the technology in Cotecmar, see Fig. 2.

Considering the stages shown in Fig. 2, it is contemplated that the construction of the remotely controlled USV represents a value gained for the continuity of the stages to be developed in the future, which will strengthen the technical capacity of human resources in Cotecmar for the appropriation of new knowledge, application and materialization of innovative and scalable products in the maturity of Industry 4.0 in the fluvial, maritime and naval sector, as well as progress in the scale of commercial maturity.

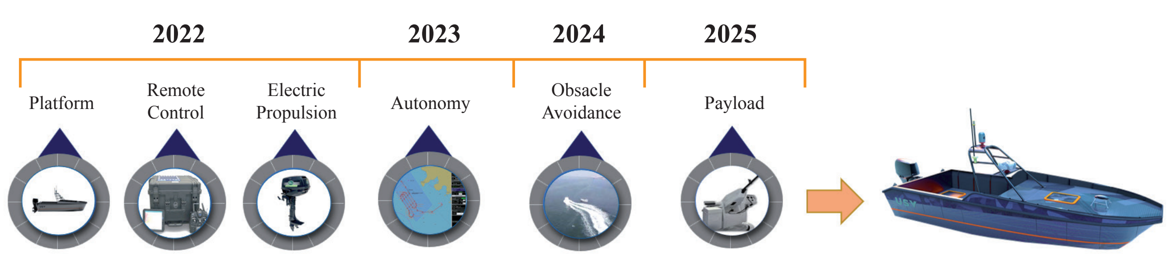
The following are the stages that are expected to be executed sequentially in order to give continuity to the development, as follows:

- Autonomy: At this stage the payload will be integrated and will integrate the required software for perception and monitoring of the environment, with the ability to detect obstacles and give some alerts.
- Obstacle avoidance: At this stage it is expected to select and integrate to the vehicle software the algorithm that allows obstacle avoidance, autonomous navigation in restricted areas, collision alerts and fail-safe decision making.
- Payload: At this stage it is expected to have the ability to integrate different sensors / payload, according to the type of mission of the vehicles that will be realized in the future USV, for the application or operation in potential sectors such as the port sector, naval oil & gas, etc.

Conclusions

1. It is expected that the applications of Industry 4.0 technologies will increase in the naval, maritime and riverine sector with the advance in the levels of automation for the assistance and operation of vessels; therefore, it is considered relevant to continue with the strengthening of technical capacities that allow for productivity and better competition in the regional market.
2. Follow-up and participation in the generation of regulations for autonomous and unmanned vehicles provides a strategic vision for USV applications in Colombia and Latin America.
3. The construction of a prototype vehicle for the development and phased implementation of autonomy levels in vessels in Cotecmar is considered as a tool to trace the maturity path of a self-development.

Fig. 2. Proposed roadmap for the development and maturity of autonomous and unmanned vehicle technology.



References

[1] «Armada República de Colombia, «Plan de Planeamiento de Desarrollo Naval 2042 , primera edición,» Bogotá - Colombia., 2020.

[2] K. SCHWAB, «La Cuarta Revolución Industrial (P.Gayozzo y F. López de Pomar Trad.),» Futuro hoy, vol. 1, nº 1, pp. 6-10, 2020.

[3] COTECMAR, «Direccionamiento Estratégico de Cotecmar 2019-2034,» Cartagena - Colombia, 2019.

[4] H. A. BUCHEIM DUARTE, «Obtención del modelo de velocidad para el vehículo de superficie no tripulado "Sabalo" y su futura actualización en el desarrollo del sistema de control de navegación de la embarcación.,» Escuela Naval de Cadetes Almirante Padilla, Facultad de Ingeniería Naval., Cartagena de Indias. Colombia, 2018.

[5] GRUPO INNOVA, «USV SÁBALO, Entregable E 2.3.1 Documento de especificaciones.,» España, 2013.

[6] L. AMADOR REYES Y N. CORREA RAMOS, «Implementación del sistema de control de camara PTZ por radiofrecuencia en Vehiculos de Superficie no Tripulados "SABALO",» Escuela Naval de Cadetes Almirante Padilla, Facultad de Ingeniería Naval. , Cartagena de Indias. Colombia. , 2017.

[7] D. M. CUBIDES GARZON Y M. A. ARIZA ZULUAGA, «Vehículos de superficie no tripulados: avance de la tecnología y su aplicación en la Armada de la República de Colombia,» de Tecnologías de la cuarta revolución industrial y su aplicación en la Armada Nacional de Colombia, Bogota D.C. Colombia, Universidad del Rosario., 2022, pp. 195-234.

[8] K. BLOMBERG Y J. GROSS, Conceptual Study of a USV for the Swedish Navy, Swedish Defense Material Administration (FMV), 2014.

[9] Deparment of the Navy, The Navy unmanned surface vehicle (USV) Master Plan, Estados Unidos, 2007.

Barriers and enablers for developing sustainable supply chains in the shipbuilding industry

Barreras y facilitadores para la implementación de cadenas de suministro sostenibles en la industria naval

DOI: https://doi.org/10.25043/19098642.248

Erika Tatiana Ruíz Orjuela [1]
Wilson Adarme Jaimes [2]

Abstract

Sustainability is a topic of interest on the agenda of governments, companies and academics worldwide. Changing practices in supply chain management to decrease environmental and social impact has become more important. The shipping industry is also facing these challenges and is looking to incorporate new technologies and processes for supply chain management. However, depending on the context, previous studies have identified different factors that influence the successful implementation of sustainable practices. The objective of this study is to review the barriers and facilitators that influence the implementation of sustainable supply chain management policies in the shipping industry through a literature review and evaluate their relationships.

Key words: Sustainability, Marine, Logistics, Supply chain.

Resumen

La sostenibilidad es un tema de interés en la agenda de los gobiernos, las empresas y académicos a nivel mundial. Cambiar las prácticas en la gestión de la cadena de suministro para disminuir el impacto ambiental y social se ha vuelto más importante. La industria naval se enfrenta también a estos desafíos, por lo que busca la incorporación de nuevas tecnologías y procesos para la gestión de su cadena de suministro. Sin embargo dependiendo del contexto estudios previos han identificado diferentes factores que influyen en el éxito de la implementación de prácticas sostenibles. El objetivo de este estudio es realizar una revisión sobre las barreras y facilitadores que influyen en la implementación de políticas de gestión sostenible de la cadena de suministro en la industria naval a través de una revisión de literatura y evaluar sus relaciones.

Palabras claves: Sostenibilidad, Naval, Logística, Cadena de suministro.

Date Received: November 21st, 2022 - *Fecha de recepción: 21 de noviembre de 2022*
Date Accepted: February 25th, 2023 - *Fecha de aceptación: 25 de febrero de 2023*

[1] Universidad Nacional de Colombia. Bogotá, Colombia. Email: erruizo@unal.edu.co
[2] Universidad Nacional de Colombia. Bogotá, Colombia. Email: wadarmej@unal.edu.co

Introduction

As society becomes aware of global warming and environmental problems, companies are increasingly questioning the environmental sustainability of their production processes and supply chains [1], [2]. This applies to a wide variety of sectors. However, those related to marine transportation have received particular attention, as they generally develop their ship and equipment design, construction, and improvement processes close to at-risk and protected ecosystems such as marine and river ecosystems [3]-[5]. In addition, companies must keep up with environmental practices for competitive reasons.

The concept of sustainability in the supply chain is defined as the integration of environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to consumers, as well as end-of-life management of the product [1], [6] - [8].

The shipping industry is concerned about the environment. Especially those related to environmental problems, such as resource depletion and pollution caused by transportation. Cruise ships and cargo ships account for almost 30% of global emissions of smog-forming sulfur oxide and almost 10% of SO_2 emissions from burning fossil fuels [5], [9]-[11]. Entities such as the IMO (International Maritime Organization), have issued standards that seek to reduce the amount of greenhouse gas emissions generated by a ship. Based on the above, the shipping industry has characteristics that make it interesting and relevant to study sustainability practices in the supply chain. A challenge for organizations operating in naval supply chains is to balance gaining a competitive advantage and acting in a sustainable manner while maintaining reputation, legitimacy, and credibility, as well as meeting the expectations of various stakeholders. As a result, sustainability issues along the supply chain can affect the financial and operational performance of organizations [6]. Therefore, sustainable supply chain management has become an important research topic. This research topic combines the concepts of supply chain management and sustainability. Three dimensions of sustainable development, economic, environmental, and social performance are considered [9].

Studies on green or sustainable supply chain management focus on the internal operations of the pivot company or on the green management practices developed within it [8]. Previous studies identified that facilitators are context and sector specific, therefore the objective of this paper is to build a theoretical framework on barriers and facilitators that influence the implementation of sustainable Supply Chain practices in the shipbuilding industry [11], [12]. Based on the above, the specific contributions of this paper are derived from the following research questions: What barriers affect the implementation of sustainable supply chain practices in the shipbuilding industry and how organizations seek to overcome them? What facilitators affect the implementation of sustainable supply chain practices in the shipbuilding industry and what is their importance?

Methodology

To meet the objectives of this article, two phases are carried out, the first is a literature review that aims to map and review the existing literature to identify research opportunities and define the frontiers of knowledge and in the second phase a MICMAC Analysis- Cross Impact and Multiplication Matrix applied for a classification into four categories: autonomous, dependent, linkage and independent [13].

Based on the PRISMA *(Preferred Reporting Items for Systematic reviews and Meta-Analyses)* protocol for scoping review [14], the following are the guiding aspects for the literature review.

- Literature eligibility criteria: The eligibility criteria have been structured based on the type of participants (population), the concept, context, and the types of evidence sources. Priority is given to scientific articles from worldwide academic databases.

- Types of participants: Barriers and enablers to the implementation of sustainable practices in the marine supply chain.
- Context: shipbuilding industry.
- Sources: literature reviews, articles.
- Search strategy: Given the nature of the review, searches in indexed databases will be used.
- Search in indexed database: The electronic database to be consulted is SCOPUS. It will be complemented with a search for additional publications using the "snowball" methodology. The following search equation was designed: *TITLE-ABS-KEY (shipbuilding) AND TITLE-ABS-KEY ("green*" and "supply chain*")*
- Selection of sources: The list with the bibliographic references identified in the searches of indexed databases will be downloaded in a library of the Mendeley program. The initial screening, considering the title of the publication and the abstract, will be performed independently. Subsequently, the full text of the selected references will be obtained.
- Content analysis: The identified literature will be used to answer the guiding questions of this study.

Results

Literature review.

After performing the search equation in the SCOPÚS database, a total of 16 articles were identified, then the VosViewer® software was used to perform a bibliometric analysis of the results obtained. To perform this analysis, the results were first cleaned in each of the databases, eliminating duplicate records and applying a cleaning list to group the authors; the *thesauri* were also applied. The results of the bibliometric analysis are presented below.

According to the following figure, the number of related articles has had an increasing trend over time, with the majority of publications in the last 5 years.

In terms of countries, according to Fig. 2, the United States, China, the Netherlands, France, Norway, Spain, Turkey and the United Kingdom are identified as the leaders in the number of articles produced on this topic. In general, the geographical dispersion of these organizations indicates that the research has been of interest to institutions and research centers worldwide and has had a recent interest in this field of research.

To identify emerging themes, a keyword analysis was performed using *VOSviewer*. Co-word analysis applies text mining techniques to article titles, abstracts, and keywords. The relationship between keywords is determined based on the number of articles in which the keywords appear together [15]. To perform the analysis, the results of the search equation were combined. Coding errors in sources, links and cited references were corrected

Fig. 1. Number of articles published per year.

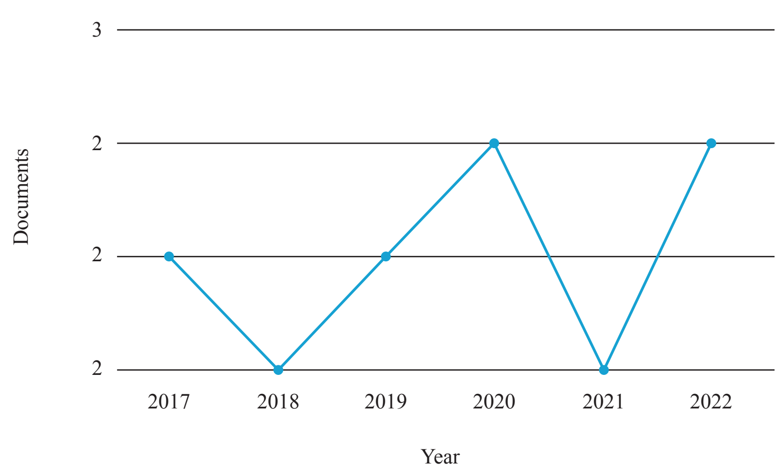
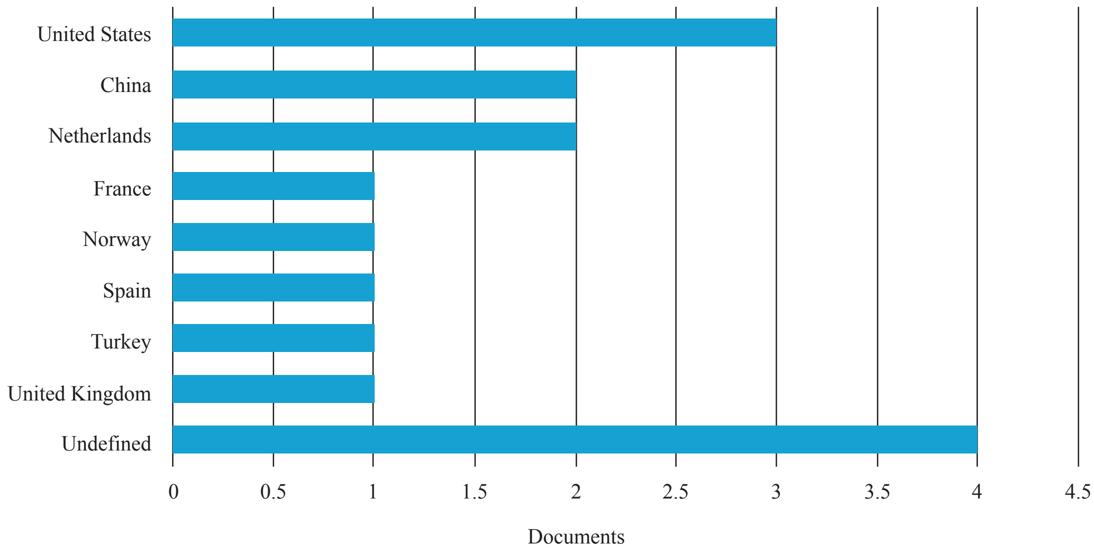
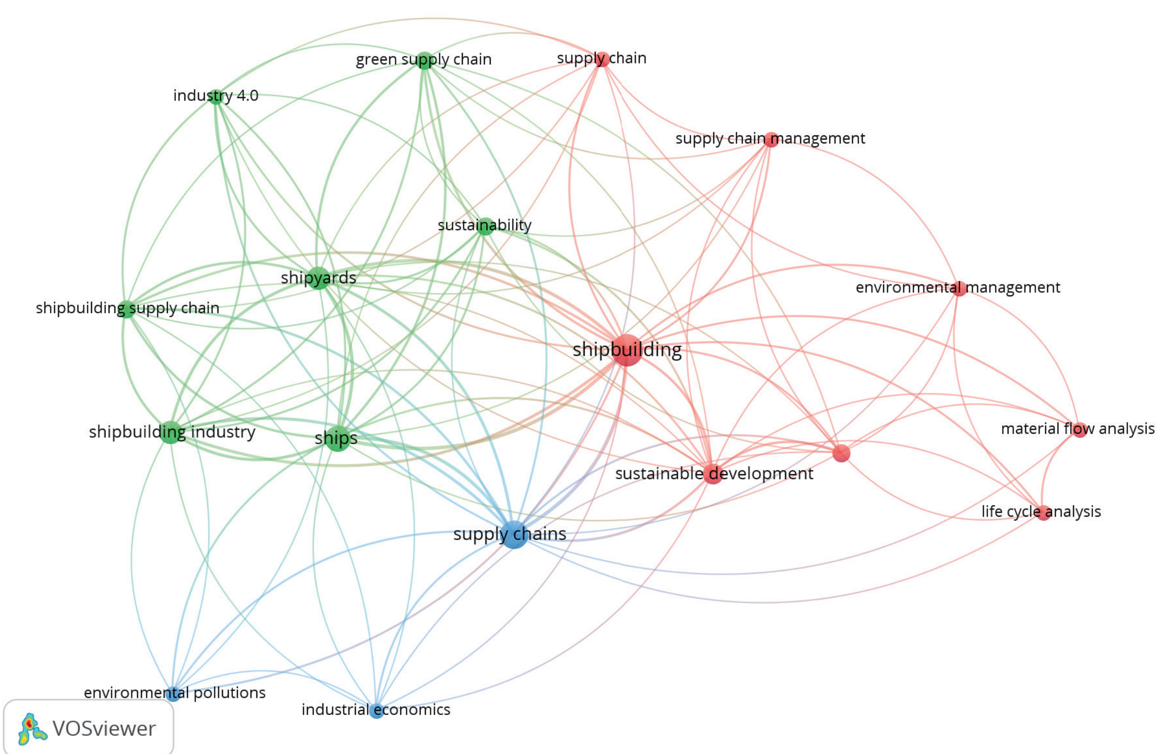


Fig. 2. Main countries.



for further analysis. From this analysis 3 clusters emerged interlinked by the words in the center of the map: "Shipbuilding", "supply chain management" "sustainability" indicating a high interrelation of the keywords with the other clusters: 1) sustainable supply chain practices, 2) shipbuilding industry mission processes and 3) measurements or effects on the environment (Fig. 3).

Fig. 3. Keyword co-citation network.



The culture of sustainability in all actors that are part of the chain is essential to align strategies. Collaboration among actors has been defined as the collaborative paradigm that is essential to achieve competitive advantage through sustainable supply chain management. However, the authors indicate that depending on the national context in which an organization operates these enablers may vary [16]. In addition, technological integration and information exchange are also considered fundamental; in this case, coordination mechanisms that contribute to and promote integration among actors with the sustainability of the supply chain as the central axis are discussed [3].

Enablers.
A requirement for the successful implementation of sustainability practices in the supply chain is related to the commitment of top management [3], however, as for the other employees of the organization, their participation and specific support for the implementation of practices is also required [3]. Research also highlights the allocation of resources for purchasing, training and other elements required for sustainable practices [1].

Likewise, the culture of sustainability in all the actors that are part of the chain is essential to align strategies. Collaboration among actors has been defined as the collaborative paradigm that is essential to achieve a competitive advantage through sustainable supply chain management. However, the authors indicate that depending on the national context in which an organization operates these enablers may vary [16]. In addition, technological integration and information exchange are also considered fundamental; in this case, coordination mechanisms that contribute to and promote integration among actors with the sustainability of the supply chain as the central axis are discussed [3].

Barriers.
Consistent with the previous section, the authors identify the lack of commitment and support from top management, the lack of commitment and understanding by all stakeholders and the fact of not having practices aligned with mission strategies as barriers to the successful implementation of sustainable practices. In addition, resource and financial constraints act as barriers. Furthermore, the lack of structures and processes, i.e. the level of organizational maturity of the companies also limit their successful implementation.

On the other hand, aspects at the national level, such as norms and regulations, restrict or limit the sustainable behavior of the chain, since only compliance with standards is guaranteed without generating innovation processes on sustainability. In addition, purchase decisions based on price or lack of demand for sustainable products are barriers that are related to customer behavior [11], [17]. Another significant aspect of potential barriers is related to the buyer-supplier relationship. Finally, lack of cooperation, unwillingness to share information, considering environmental and social standards as additional costs that do not add value, limit the implementation of sustainable practices [2], [4].

Relationship between barriers and facilitators.
Based on the documents analyzed, the factors identified, which can act as barriers or facilitators depending on their absence and development at the organizational level, are presented in general (Table 1).

Considering that the objective of the work is to prospectively know the relationship between these factors in the shipbuilding industry, the academic exercise was based on the articles initially identified and based on that the researchers performed the MICMAC analysis, which is presented in Fig. 4.

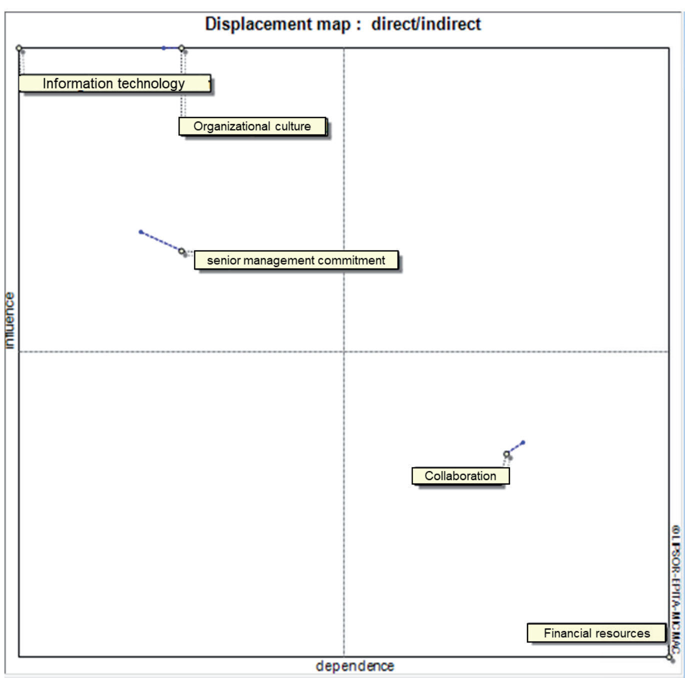
The determining factors are located in the upper left quadrant, part of the system depends on these and can become facilitators or barriers, in this quadrant are: Information technologies, organizational culture and top management commitment. The results factors are in the lower right quadrant, where collaboration and financial resources are located, these factors require monitoring to verify the effectiveness of the system.

Finally, Fig. 5 of direct influence shows that there

Table 1. Factors influencing the implementation of sustainable practices.

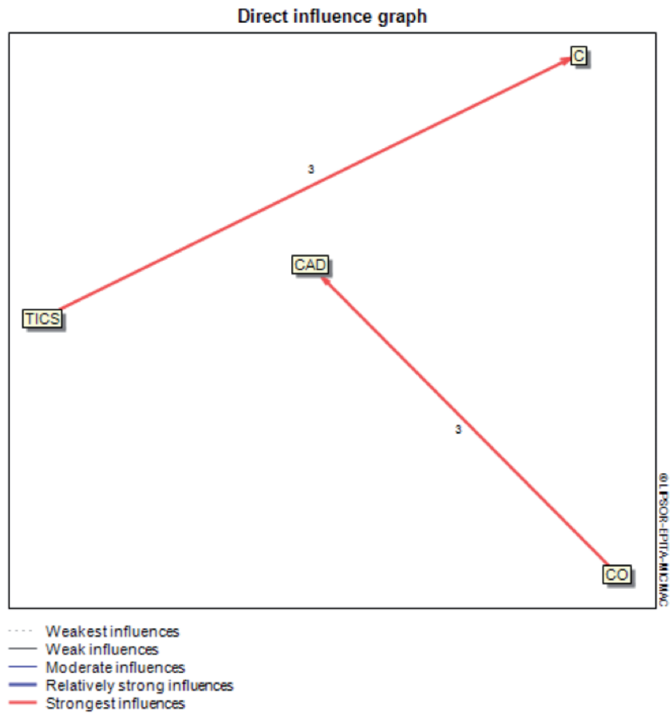
Factor	Description	References
Financial resources	Implementing sustainable practices requires financing and commitment in terms of money and time from all actors in the chain. In the future, these practices will translate into financial benefits and recognition in the sector.	[2], [5], [12], [17]
Senior management commitment	Senior management must lead projects that implement sustainability practices, coordinate activities and align the organization's strategic objectives with those of the supply chain.	[6], [7], [18]
	Concern for the environment and society must be an inherent element in all the people who are part of the organization, this will promote the understanding and commitment of the stakeholders.	[4], [8], [11], [12]
Organizational culture	Collaboration among actors promotes access to sustainable technologies and practices at lower cost and creates greater competitive advantage for the entire chain.	[7], [10], [12]
Collaboration	Organizations focus on technologies and information to reduce pollution and waste. Cleaner technologies help minimize waste and pollution in the production process, and improve economic and environmental performance.	[2], [17]
Information technology	Implementing sustainable practices requires financing and commitment in terms of money and time from all actors in the chain. In the future, these practices will translate into financial benefits and recognition in the sector.	[2], [5], [12], [17]

Fig. 4. MIC MAC of factors.



are two strong relationships between these factors which correspond to: Information technology (ICT) and collaboration (C) and the relationship between top management commitment (SMC) and organizational culture (OC). The above allows validating the information found through the content analysis of the articles.

Fig. 5. Direct relationship of factors.



Conclusions

This paper adds to the emerging field of study that seeks to investigate the context for implementing successful sustainable supply chain practices in the marine sector. This paper presents a theoretical framework on barriers and enablers. In the first phase, a literature review was presented to identify these factors, then based on content analysis the relationships between them were evaluated. The identification of enablers helps supply chain practitioners and strategic decision makers to identify key elements that require attention to implement practices. Barriers are a major obstacle during the implementation phase and pose significant challenges and require special attention. Based on the MICMAC analysis, the determining factors are identified as Information Technology, organizational culture and top management commitment. The objective is to make them facilitators.

The recommendations based on the results obtained are: first, companies in the shipbuilding sector can increase their level of implementation practices through investment in information technology that encourage collaboration, information exchange between chain actors in a proactive and collaborative manner. Secondly, they could start training their employees in sustainable practices such as design for the environment, life cycle analysis, recycling, and other environmentally proactive practices to create environmental awareness within the company as well as in supplier companies and customers along the entire supply chain. Finally, the commitment of top management, which is measured not only through the financial resources granted for the implementation of sustainable practices but also through improved coordination and collaboration among actors, to achieve successful implementation of these practices throughout the supply chain.

Finally, it should be noted that there is a possibility of bias in the analysis, which could be the objective of future research using quantitative techniques. In addition, the MICMAC analysis does not identify the relative weights of the variables represented in the model, so a more in-depth analysis using a structured questionnaire survey is required.

References

[1] A. A. HERVANI, M. M. HELMS, AND J. SARKIS, "Performance measurement for green supply chain management," Benchmarking An Int. J., vol. 12, no. 4, pp. 330-353, Jan. 2005, doi: 10.1108/14635770510609015.

[2] Y. LI AND J. YANG, "How Government Subsidy Impacts on the Supply Chain Decision for LNG-Fuelled Ships," Math. Probl. Eng. vol. 2022, 2022, doi: 10.1155/2022/1680489.

[3] V. M. RAO TUMMALA, C. L. M. PHILLIPS, AND M. JOHNSON, "Assessing supply chain management success factors: a case study," Supply Chain Manag. An Int. J., vol. 11, no. 2, pp. 179-192, Jan. 2006, doi: 10.1108/13598540610652573.

[4] P. GILBERT, P. WILSON, C. WALSH, AND P. HODGSON, "The role of material efficiency to reduce CO2 emissions during ship manufacture: A life cycle approach," Mar. Policy, vol. 75, pp. 227-237, 2017, doi: 10.1016/j.marpol.2016.04.003.

[5] M. TANTAN AND H. CAMGÖZ-AKDAĞ, "Sustainability concept in Turkish shipyards," WIT Trans. Ecol. Environ. vol. 241, pp. 269-281, 2020, doi: 10.2495/SDP200221.

[6] J. W. STRANDHAGEN, S.-V. BUER, M. SEMINI, E. ALFNES, AND J. O. STRANDHAGEN, "Sustainability challenges and how Industry 4.0 technologies can address them: a case study of a shipbuilding supply chain," Prod. Plan. Control, vol. 33, no. 9-10, pp. 995-1010, 2022, doi: 10.1080/09537287.2020.1837940.

[7] P. DESAI, R. SAREMI, S. HOFFENSON, AND C. LIPPIZI, "Agile and affordable: A survey of supply chain management methods in long lifecycle products," 2019, doi: 10.1109/SYSCON.2019.8836861.

[8] M. C. J. CANIËLS, E. CLEOPHAS, AND J. SEMEIJN, "Implementing green supply chain practices: an empirical investigation in the shipbuilding industry," Marit. Policy Manag. vol. 43, no. 8, pp. 1005-1020, 2016, doi: 10.1080/03088839.2016.1182654.

[9] G. CLANCY, M. FRÖLING, AND G. PETERS, "Ecolabels as drivers of clothing design," J. Clean. Prod. vol. 99, pp. 345-353, 2015, doi: https://doi.org/10.1016/j.jclepro.2015.02.086.

[10] M. C. J. CANIËLS, E. CLEOPHAS, AND J. SEMEIJN, "Implementing green supply chain practices: An empirical investigation in the shipbuilding industry," in 75th Annual Meeting of the Academy of Management, AOM 2015, 2015, pp. 323-328, doi: 10.5465/AMBPP.2015.49.

[11] H. WANG AND Y. ZHAO, "Studies of the construction and evaluation of green shipbuilding supply chain system," Energy Educ. Sci. Technol. Part A Energy Sci. Res., vol. 32, no. 5, pp. 4361-4366, 2014.

[12] M. BIRON, Industrial Applications of Renewable Plastics: Environmental, Technological, and Economic Advances. Les Ulis, France: Elsevier Inc., 2016.

[13] P. K. BOCK, "Micmac," vol. v. 15. Smithsonian Institution, Washington, D.C., pp. 109-122, 1978.

[14] S. BEST AND S. J. WILLIAMS, "What Have We Learnt About the Sourcing of Personal Protective Equipment During Pandemics? Leadership and Management in Healthcare Supply Chain Management: A Scoping Review," Front. Public Heal. vol. 9, 2021, doi: 10.3389/fpubh.2021.765501.

[15] N. J. VAN ECK AND L. WALTMAN, "Software survey: VOSviewer, a computer program for bibliometric mapping," Scientometrics, vol. 84, no. 2, pp. 523-538, 2010, doi: 10.1007/s11192-009-0146-3.

[16] A. AWAYSHEH AND R. D. KLASSEN,

"The impact of supply chain structure on the use of supplier socially responsible practices," Int. J. Oper. Prod. Manag. vol. 30, no. 12, pp. 1246-1268, Jan. 2010, doi: 10.1108/01443571011094253.

[17] M. RAMIREZ-PEÑA, A. J. SÁNCHEZ SOTANO, V. PÉREZ-FERNANDEZ, F. J. ABAD, AND M. BATISTA, "Achieving a sustainable shipbuilding supply chain under I4.0 perspective," J. Clean. Prod. vol. 244, 2020, doi: 10.1016/j.jclepro.2019.118789.

[18] V. WILSON, P. WENNBERG, K. DEGRAW, AND M. FLEISCHER, "An Improved 'Make versus Buy' Strategy for Future Material Acquisiton," J. Sh. Prod. vol. 17, no. 2, pp. 87-91, 2001.

Decision-making model for propulsion system selection

Modelo de toma de decisiones para la selección del sistema de propulsión

DOI: https://doi.org/ 10.25043/19098642.249

Daniel Álvarez Berdugo [1]
Miguel A. Romero A. [2]
Juan E. Cruz [3]

Abstract

History it has become evident that the military industry and its thriving action has generated change and development in different areas, and it is to be expected that a project as ambitious as the Strategic Surface Platform - PES focuses on the impact that internal combustion systems can generate in the design, therefore an evaluation model is developed for the selection of the propulsion system of the platform, which was based on the life cycle cost and performance of the main mechanical equipment, providing an additional tool for decision making. The cost side was estimated by breaking down the ROM (Rough Order of Magnitude) acquisition costs, maintenance costs and fuel and lubricant consumption costs, which leaves the performance side evaluated under the technical characteristics, considering the criteria of performance, reliability, delivered power and installation footprint; without leaving aside the mandatory requirements such as IMO TIER III gas emissions, reduction of the acoustic signature and the use of redundancy.

Key words: Maritime pollution; Greenhouse gases; Cost Effectiveness; Energy Saving; Propulsion System.

Resumen

A través de la historia se ha hecho evidente cómo la industria militar y su pujante accionar ha generado cambio y desarrollo en las diferentes áreas, y es de esperar que un proyecto tan ambicioso como lo es la Plataforma Estratégica de Superficie – PES se enfoque en el impacto que los sistemas de combustión interna pueden generar en el diseño, por lo anterior se desarrolla un modelo de evaluación para la selección del sistema de propulsión de la plataforma, el cual fue basado en el costo del ciclo de vida y el desempeño de los equipos mecánicos principales, brindando una herramienta adicional para la toma de decisiones. La arista del costo se estimó desglosando los costos de adquisición del tipo ROM (Rough Order of Magnitude), costos de mantenimiento y costos de consumo de combustible y lubricante, lo que deja la arista de desempeño evaluada bajo las características técnicas, considerando los criterios de rendimiento, confiabilidad, potencia entregada y huella de instalación; sin dejar a un lado los requisitos de obligatorio cumplimiento como lo son las emisiones de gases IMO TIER III, la reducción de la firma acústica y el empleo de la redundancia.

Palabras claves: Contaminación marítima; Gases de efecto invernadero; Rentabilidad; Ahorro de energía; Sistema de propulsión.

Date Received: December 5th, 2022 - *Fecha de recepción: 5 de diciembre de 2022*
Date Accepted: March 1st, 2023 - *Fecha de aceptación: 1 de marzo de 2023*

[1] Technical Section PES Program - Navy Republic of Colombia. Bogotá, Colombia. Email: daniel.alvarez.ber@armada.mil.co
[2] Technical Section PES Program - Navy Republic of Colombia. Bogotá, Colombia. Email: miguel.romero@armada.mil.co
[3] Technical Section PES Program - Navy Republic of Colombia. Bogotá, Colombia. Email: juan.cruz@armada.mil.co

Introduction

The maritime industry has received a growing demand in the variation of propulsion system configurations, which are not only limited to seeking significant fuel savings, but also focus their efforts on the optimization of environmental and performance variables, which directly and indirectly affect the development of the logistics chain to produce vessels. The military industry is no stranger to these processes, and, through the navies of the different nations, it is also taking part in these requirements, generating greater demands on each of the companies involved.

In this way, the increase in standards and regulations, force to establish strict acceptance criteria on the different configurations of propulsion systems traditionally used in the maritime industry, criteria such as reduction in emission percentages, variation in speed ranges, multi-mission units, reduction in crews, technical requirements, among others.

On the other hand, facing the challenges caused by the scarcity of fossil fuels and the problematic of its effects on global warming, as mentioned by Zhu (2018), for the design in the process of propulsion system optimization, international regulations have been promulgated, such as the energy efficiency design index (EEDI) and the ship energy efficiency management plan (SEEMP), aimed at reducing the growth rate of fuel consumption and greenhouse gas (GHG) emissions in the shipbuilding sector *(Zhu et al., 2018)*. Thus, different authors have shown the need to develop energy efficient ships, working in accordance with environmental regulations and giving rise to proposals for hybrid propulsion and generation designs and configurations *(Geertsma, Negenborn, et al., 2017; Geertsma, Vollbrandt, et al., 2017)*.

Therefore, and in summary, the objectives achieved in the development of this work include:

- Development of a viable and robust methodology for the evaluation of a life cycle model (both in costs and environmental impacts) and performance model for different propulsion system arrangements.
- To structure the evaluation model of the propulsion configurations CODAD (Combined Diesel and Diesel), CODOE (Combined Diesel or Electric), CODAG (Combined Diesel and Gas) and CODOG (Combined Diesel or Gas) with growing tendency in the market, which allows the Colombian Navy to technically identify the optimal propulsion configuration for the fulfillment of its mission.
- Through the appropriate parameters perform a comparative analysis of the propulsion configurations CODAD, CODOE, CODAG and CODOG offered by the market, using the propulsion evaluation model proposed by *(Morales E. et al., 2016b, 2016a)*. The results of this analysis will provide the Colombian Navy with sufficient arguments for decision making in the selection of the propulsion system configuration.

The structure of the article begins with a description of the decision-making model and the approaches available in the literature (research background), followed by a description of the life cycle cost and performance model, based on the analysis of four different propulsion system arrangements currently available in the market. Finally, based on the results obtained, conclusions are proposed showing the arrangement selected for the PES project, which best fits the established design parameters.

Theoretical Framework.

It is clear that there is a progressive trend towards partial or full electric propulsion, examples of which have been the British Navy's Type 23 ASW frigate, the German Navy's F125, the Spanish Navy's F110, the Italian and French Navy's FREMM, the Republic of Korea Navy's FFX-II frigate, and the Finnish Navy's SQ2020 frigate programs *(Ohmayer, 2012; Royal Navy U.K., n.d.; Silatan et al., 2014)*.

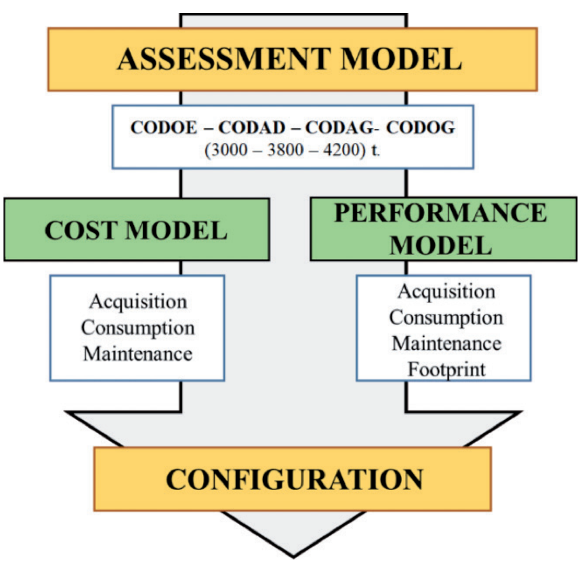
Despite this trend towards hybrid systems, making the decision to turn to their implementation becomes a long and tedious process that includes many angles (from the design phase to the retirement phase), even more so, knowing that the decisions made during the early design phases will generate a significant impact throughout the entire life cycle. This is why this approach has become a design tool for strategic decision making throughout the entire life cycle *(Zhu et al., 2018)*.

Table 1. PES design parameters.

General data	Value
Life time (years)	30
Hours of operation per year	2500
Displacement (ton)	3000-3800-4200
Crew (und)	100 trip +30
Maximum range	4000nm@14.5knots

In this sense, the evaluation model for the selection of the ESP propulsion system, shown in Fig. 1, was based on the parameters established in Table 1, considering the cost in the projected 30-year life cycle, associating the costs of acquisition, maintenance and operation of the equipment, also considering the cost of fuel and lubricant, as well as the performance of each configuration, evaluating the performance, reliability, power and footprint.

Fig. 1. Model selection propulsion system.



Power Analysis.

The development of a decision making model for the selection of the propulsion system became an essential part of the development process of the Strategic Surface Platform; managing to meet the requirements of speed and power of the ship, where undoubtedly, the Colombian Navy has considered each of the variables commonly evaluated in the maritime industry, such as rising costs or scarcity of fossil fuels, which lead to rethink the traditional systems or arrangements installed on warships, making these decisions are oriented towards more efficient solutions. However, the challenges for this process increase considering the additional demands, such as the speed-power profiles at which ships usually work, variability in electrical power ranges, and even the lack of resources for asset maintenance during the life cycle, which make the optimization process even more complex under this scenario.

Based on this, an evaluation was made of the propulsion system configurations existing in the market used in modern platforms, such as CODOE, CODAD, CODAG and CODOG, including the recommended operating variables for each gear at different platform speeds, analyzing acquisition costs, maintenance costs, dimensions, weights, technical specifications, and fuel consumption.

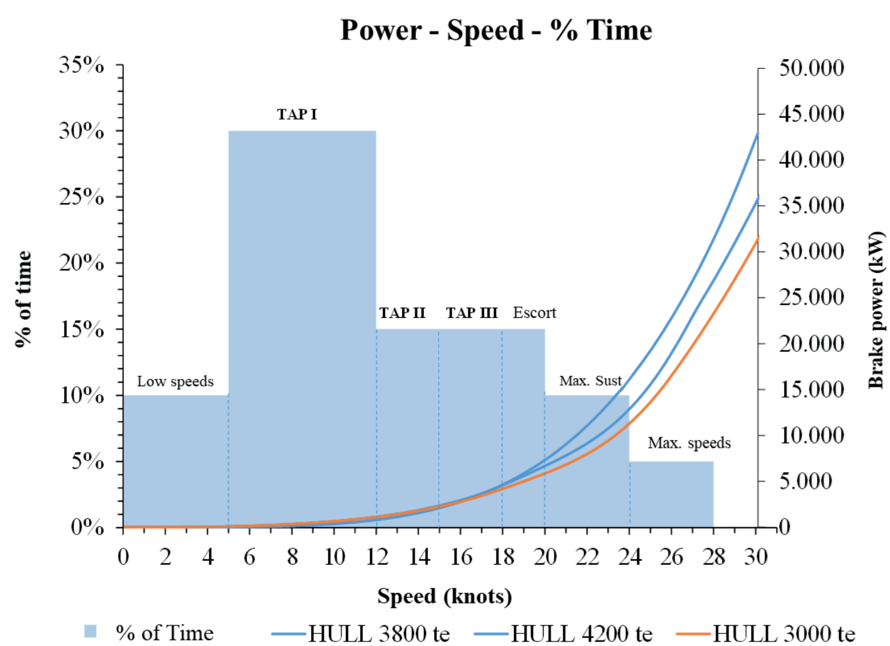
For the purposes of this analysis, propulsion configurations were selected for three types of vessels with expected displacements of 3000, 3800 and 4200 tons, considering high power diesel engines to supply each of these requirements, evaluating seven (07) possible speed ranges for each of the selected displacements as shown in Table 2.

Likewise, using the MaxSurf toolTM in its Resistance module, the statistical methodology for displacement vessels established by Fung and Holtrop *(Caputo, 2010; Holtrop & Mennen, 1977)* was applied. *(Caputo, 2010; Holtrop & Mennen, 1977)*. The statistical methodology for displacement vessels established by Fung and Holtrop *(Caputo, 2010; Holtrop & Mennen, 1977)* was applied to obtain the predictions of drag and

Table 2. Power required for each array.

Operation	Speed (knots)	PB (kW)	PB (kW)	PB (kW)
Low Speed	5	104	103	19
TAP I	12	1203	1215	819
TAP II	15	2217	2315	2148
TAP III	18	4554	5025	4721
Escort	20	6040	6893	7444
Max. Sustained	24	12590	14353	16364
Max. Speed	28	23622	27260	31853

Fig. 2. Brake power curve and % operating time as a function of speed profile.



effective power, as well as the power to the brake using a total efficiency margin of 50%.

Configuration Analysis.

CODOE configuration

In this configuration, four engines satisfy the different speeds of the operational profile, requiring four diesel engines (MD) for maximum speed and two engines (diesel or electric) (G) for transit and patrol speeds, analyzing five different engine arrangements and brands.

CODAD configuration

For this configuration, four diesel engines satisfy the different speeds of the operational profile, requiring all four for maximum speed and two engines for transit and patrol speeds, also analyzing five different engine arrangements and makes.

CODAG configuration

In this case, the gas turbine (TG) provides the power required to replace the engines, however, the gearbox (ER) becomes a critical element, since failure would leave the vessel without propulsion.

Fig. 3. CODOE Configuration Representation.

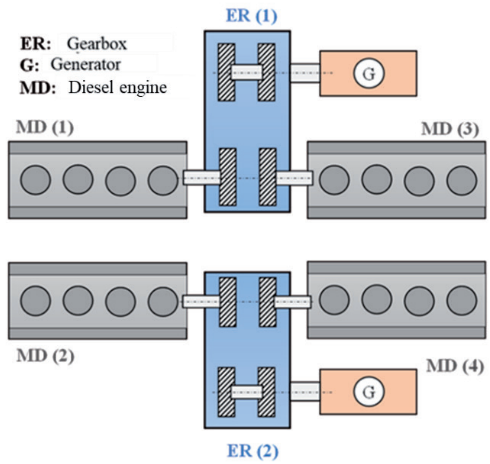


Fig. 4. Representation of CODAD configuration.

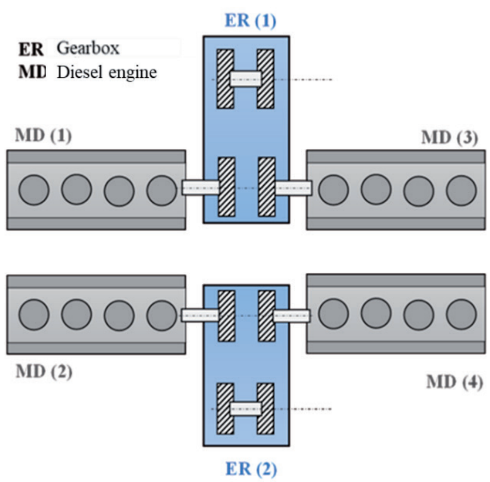
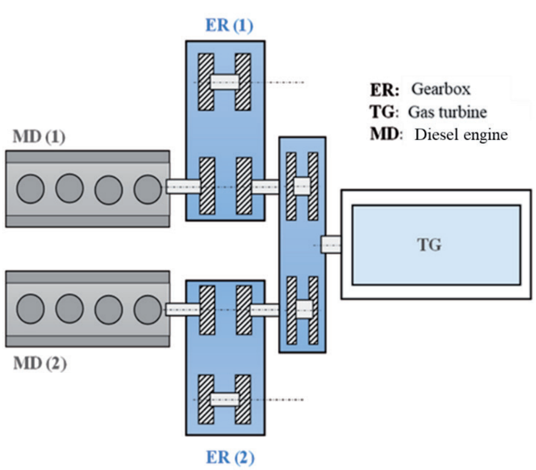


Fig. 5. Representation of CODAG and CODOG configuration



CODOG configuration

The distribution of equipment for this arrangement is the same as in CODAG, the difference lies in the requirements of the turbine to reach maximum speed without the use of diesel engines, additionally the box will have the mechanism to clutch or not the diesel engines. Eleven different engine arrangements and brands were also analyzed.

In this sense, a total of 30 different arrangements were evaluated for each of the proposed vessels of 3000, 3800 and 4200 tons, as shown in Table 3.

Cost Model.

The model estimated the relative costs of acquisition and operation in each proposed configuration, through the analysis of the cost of acquisition of type (ROM), maintenance and consumption of fuel and lubricant, determined for each of the stipulated configurations (to facilitate the compression of the process, the results obtained for the displacement of 3000 t. are presented (see Fig. 6), as follows:

- Acquisition cost: includes the cost of propulsion engines, i.e., each configuration includes the cost of diesel engines, electric motors and/or gas turbines.
- Consumption: the calculation of fuel consumption in the life cycle is considered for 30 years. This consumption was calculated according to the specific fuel consumption information in gr/kWh of the equipment of each configuration, using the established operational profile.
- Maintenance: maintenance was considered for a period of 30 years, including consumables for the recommended cyclic or general preventive maintenance, and considering the design parameter of 2,500 operating hours for this projection.

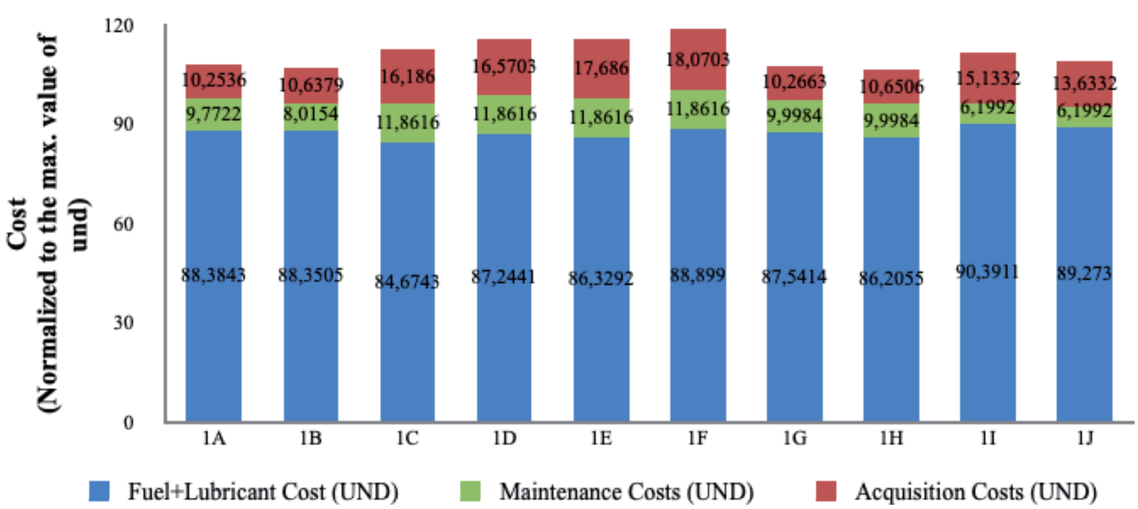
Performance Model.

To evaluate the technical characteristics of the propulsion configurations and quantitatively compare the different proposals, the performance model was developed using the analytical

Table 3. Configurations analyzed by displacement.

3000 t.		3800 t.		4200 t.	
Code	**Configuration**	**Code**	**Configuration**	**Code**	**Configuration**
1A	CODAD 3	2A	CODOE 3	3A	CODAD 2
1B	CODOE 3	2B	CODOG 3	3B	CODAG 2
1C	CODAG2	2C	CODOG+PTI 3	3C	CODOG 2
1D	CODAG + PTI 2	2D	CODAG 2	3D	CODAD 1
1E	CODOG 2	2E	CODOG 2	3E	CODOE 1
1F	CODOG + PTI 2	2F	CODAG 2	3F	CODOG 1
1G	CODAD 1	2G	CODOG 2	3G	CODAG 1
1H	CODOE 1	2H	CODAG+PTI 2		
1I	CODOG 1	2I	CODOG+PTI 2		
1J	CODAG 1	2J	CODAD 1		
		2K	CODOE 1		
		2L	CODOG 1		
		2M	CODAG 1		

Fig. 6. Life Cycle Cost Reference Image - 3000 t displacement.



hierarchical process (AHP) (see Fig. 7), which allowed establishing levels according to each configuration, with weightings in the criteria and subcriteria established at each level, to give greater specificity to the determination of performance in the situation analyzed.

For the performance model is analyzed (see Fig. 8.):

I. The (geometric) footprint generated by the propulsion system where the weight/power ratio and the area required inside the engine rooms are immersed.

II. Power behavior at unit-relevant speeds

Fig. 7. Tree structure - evaluation criteria.

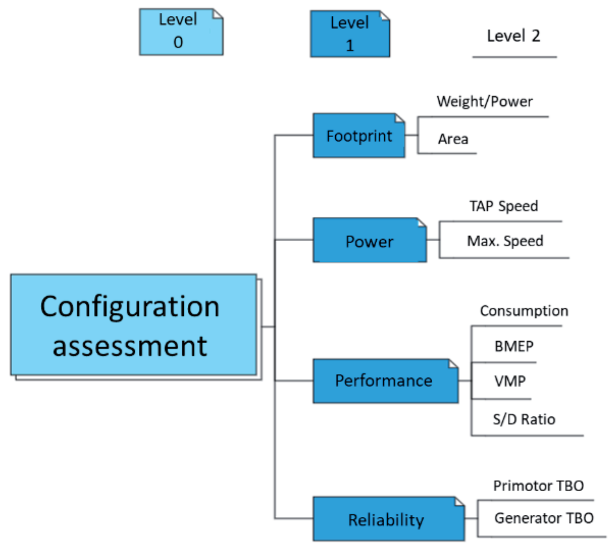
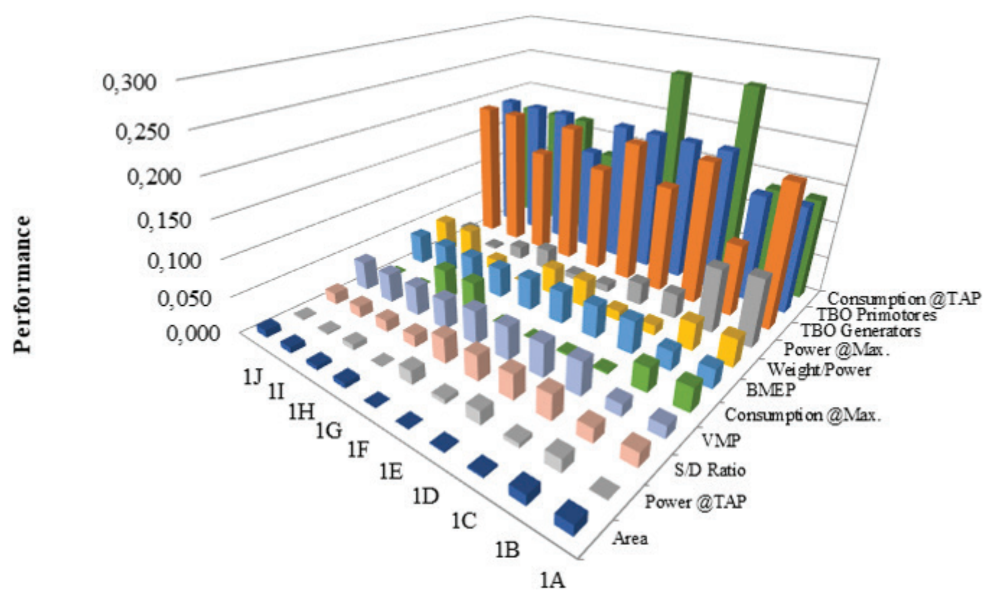


Fig. 8. Reference image of the Performance Result - 3000 t displacement.



(TAP and maximum).

III. Performance is evaluated from four aspects such as fuel consumption, brake mean effective power (BMEP), piston mean velocity (VMP) and piston stroke to diameter ratio (S/D).

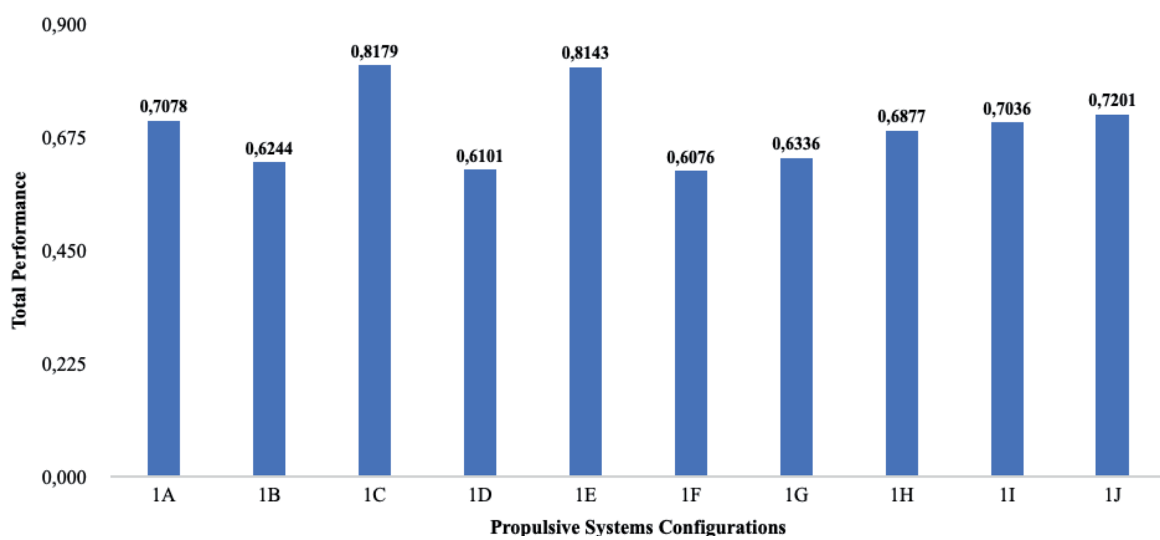
IV. Reliability presented as the time between overhauls (TBO) for prime movers (diesel engines and turbines) and for generators.

Likewise, using the matrix of pairwise comparisons (AHP methodology) of technical characteristics of each configuration evaluated by the Corporación de Ciencia y Tecnología para el Desarrollo de la Industria Naval Marítima y Fluvial - COTECMAR and the panel of experts of the Colombian Navy - ARC, the weights of each criterion were determined, to subsequently evaluate the

Table 4. Curves by criteria and levels.

Criteria	2do Level	3er Level	Curve
Performance	Consumption	Transit and Patrol	Exponential Dec
		Maximum Speed	Exponential Dec
	BMEP		Logarithmic
	VMP		Logarithmic Dec
	S/D ratio		Linear
Reliability	TBO Primotores		Linear Dec
	TBO Generators		Linear Dec
Power	Transit and Patrol		Exponential Dec
	Maximum Speed		Exponential Dec
Footprint	Weight/Power Area		Logarithmic Dec Linear Dec

Fig. 9. Reference image of Comparison of Alternatives - 3000 t displacement.



alternatives according to the available information, the latter using the ExpertChoice softwareTM . In this way, each level, criterion and subcriterion was weighted through curves (linear, linear decreasing, logarithmic, logarithmic decreasing, exponential, exponential decreasing, sigmoidal and sigmoidal decreasing), according to the choice of the panel of experts, based on the real needs of the Colombian Navy and that which best fits the requirements of Table 4.

From this analysis and the respective weightings for each level, the total performance shown in Fig. 9 is obtained.

Result Analysis.

The results of the cost and performance models were analyzed and determined for each arrangement and for each displacement, as follows:

- Displacement of 3000 t., Fig. 10: the most economical configurations for this situation are 1H and 1B (CODOE); and 1G and 1A (CODAD), the most expensive being 1F (CODOG) and the best performing were 1C (CODAG) and 1E (CODOG).
- Displacement of 3800 t., Fig. 11: the most economical configurations for this situation are 2K (CODOE); and 2J (CODAD), with the most expensive being 2C (CODOG+PTI) and the highest performance being 2H (CODAG+PTI) and 2I (CODOG+PTI).
- Displacement of 4200 t., Fig. 12: the most economical configurations for this situation are 3E (CODOE); and 3A (CODAD), with 3B (CODAG) being the most expensive and 3A (CODAD) and 3B (CODAG) being the highest performing.

Regarding costs, in general the CODAG and CODOG configurations represent a low maintenance cost related to the low frequency required for the execution of major repairs (Overhaul) during their useful life, however, the overall cost of the gas configuration is high, emphasizing the initial acquisition cost compared to the CODAD and CODOE configurations. On the other hand, when analyzing fuel and lubricant consumption, there is no marked trend that depends on the type of arrangement; however, its

Fig. 10. Results with 3000 t displacement.

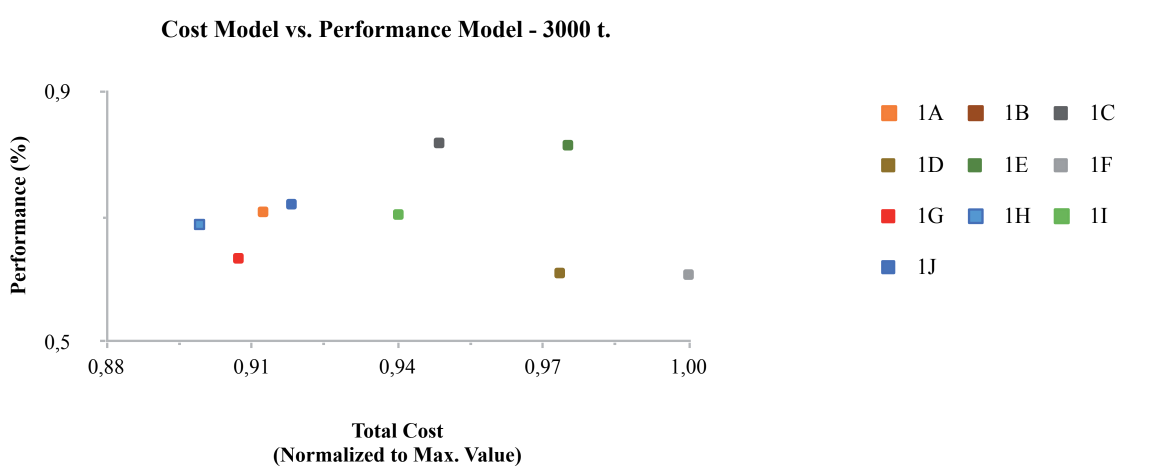


Fig. 11. Results with 3800 t displacement.

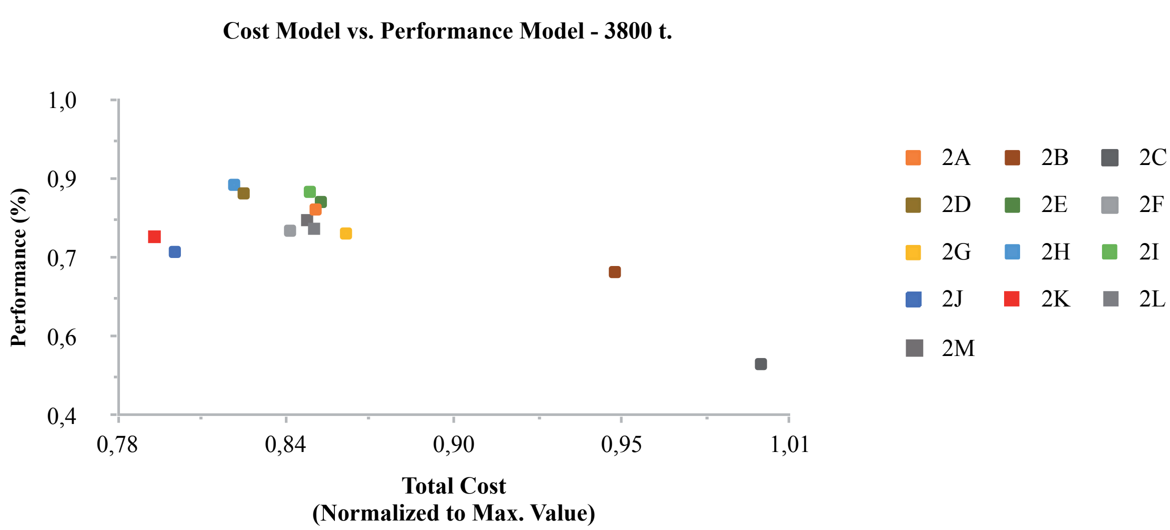
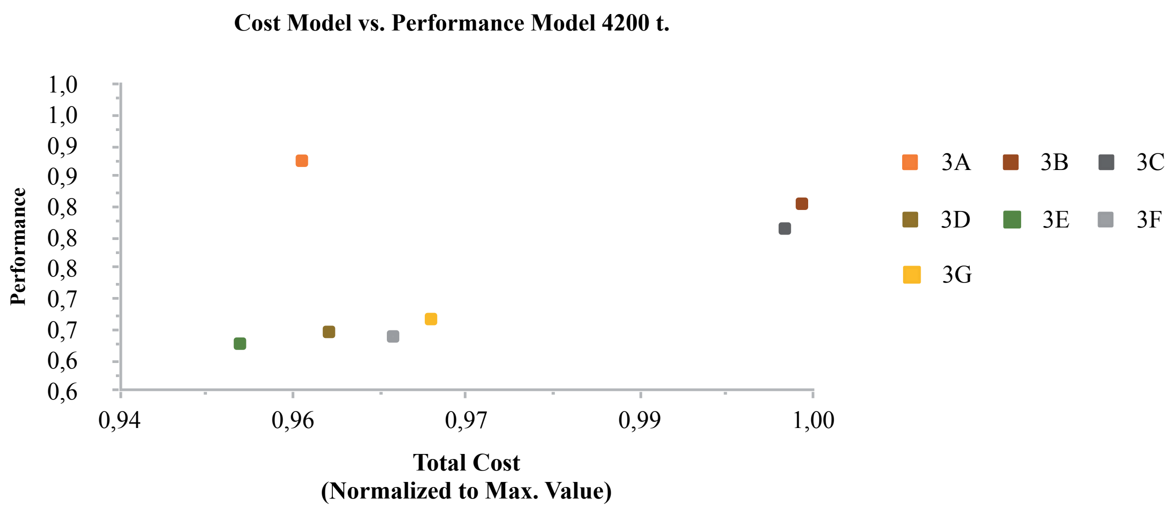


Fig. 12. Results with 4200 t displacement.



impact is directly related to the use profile, engine brand, among others.

Other analysis factors.

Emission control: is considered as a vital variable within this analysis, which is aligned with the compliance of the International Convention for the Prevention of Pollution from Ships (MARPOL) - Annex IV in the TIER III level required for ships built after 2016, in this sense, based on the results presented, aligned with what has been exposed by *(Aakko-Saksa et al., 2023; Lindstad & Sandaas, 2016)* the percentage of carbons, carbon dioxide, nitrous oxides (NOx), sulfur oxides (SOx), among others, rise mainly at low speeds and operating powers.

The above leads us to the operation profile analyzed (see Fig. 2) which will maintain low speeds 10% and speeds below 18 knots 70% of the time, this urges us to evaluate efficient alternatives that allow us to mitigate or reduce emissions levels, this is how the implementation of a hybrid system, in alternative combinations CODOE - CODAD, in this case one of diesel-electric and diesel engines (CODELAD), shows significant advantages that provide solutions to some problems raised by optimizing the operation of the machinery in each of the profiles according to the operational need and thus ensuring the proper operation in controlled environmental areas, without impacting their performance and seeking the best cost-benefit ratio *(Ammar & Seddiek). (Ammar & Seddiek, 2021).*

On the other hand, *(Silatan et al., 2014)* mentions that the high efficiency of hybrid systems (due to the variation of the configuration adapted to the speed profile) leads to low fuel consumption and causes a reduction of environmental pollution, achieving lower emissions of 4.3 gr/kwh of NOx and less than 1% of Sox, required to operate in the Emission Control Zone, contributing to regulatory compliance for the units where it is implemented.

Signatures: are not considered as a design parameter in the present work, even so, it is sought to maintain directives in Grade A equipment assemblies that classify propulsion equipment as necessary equipment for the safety and combat capability of the ship, in this way a CODELAD configuration presents significant advantages, such as the reduction of acoustic, infrared and electromagnetic signature, up to TAP II speeds (see Table 2), where Diesel-Electric propulsion is used *(Barlas & Azmi Ozsoysal, 2001). (Barlas & Azmi Ozsoysal, 2001).*

Redundancy: has been considered in the design of the vessels as one of the parameters that has been handled as a restriction, where it is necessary the ability to maintain the vessel's operations even after losing an engine room. This study considers the distribution of the electrical load in four (04) generators and that they comply with the N-1 restriction, i.e. that due to redundancy and separation, two (02) generators are located in two (02) engine rooms separated by at least one watertight bulkhead and that when losing one of these rooms, the remaining generators in operation are capable of satisfying the vital loads of the entire vessel.

Conclusions

The analysis presented in this paper is an extract of the activities developed by the ARC and COTECMAR work team, who have generated several tools, among them, the decision-making model for the selection of the propulsion system of the Strategic Surface Platform, which represents one of the steps that the program has fulfilled for the selection and validation of the platform systems, and through which it can be concluded:

- The model highlights that the CODAD (1B and 1H for 3000 t.; 2J for 3800 t.; 3A for 4200 t.) and CODOE (1B and 1H for 3000 t.; 2K for 3800 t.; 3E for 4200 t.) configurations prove to be the most economical solutions, mainly due to the low acquisition cost and low consumption presented by the configurations, in addition to their adaptability to the operating profile of the platform.
- Considering the above, the beneficial cost/performance ratio found in each of the CODAD and CODOE configurations and their hybrid CODELAD implementation, contributes to the mitigation of emissions generation as reported by different authors and thus facilitates compliance with the International Convention for the Prevention of Pollution from Ships (MARPOL) - Annex IV at TIER III level.
- Finally, for the PES project it is imperative to have a solution with a low life cycle cost, which allows its acquisition and maintenance throughout its life cycle. Therefore, and despite having a higher weight compared to other alternatives that use equipment such as turbines, the CODAD and CODOE solutions became the most appropriate for the selection, in addition to the hybrid configuration CODELAD, for its significant improvements in aspects of fuel consumption and reduction of signatures, factors of great importance for the Strategic Surface Platform.

References

AAKKO-SAKSA, P. T., LEHTORANTA, K., KUITTINEN, N., JÄRVINEN, A., JALKANEN, J. P., JOHNSON, K., JUNG, H., NTZIACHRISTOS, L., GAGNÉ, S., TAKAHASHI, C., KARJALAINEN, P., RÖNKKÖ, T., & TIMONEN, H. (2023). Reduction in greenhouse gas and other emissions from ship engines: Current trends and future options. In Progress in Energy and Combustion Science (Vol. 94). Elsevier Ltd. https://doi.org/10.1016/j.pecs.2022.101055.

AMMAR, N. R., & SEDDIEK, I. S. (2021). Evaluation of the environmental and economic impacts of electric propulsion systems onboard ships: case study passenger vessel. Environmental Science and Pollution Research, 28(28), 37851-37866. https://doi.org/10.1007/s11356-021-13271-4

BARLAS, B., & AZMI OZSOYSAL, O. (2001). The diesel-electric hybrid propulsion systems for Turskish frigates. https://www.researchgate.net/publication/266204021

CAPUTO, R. J. (2010). Impacts of Reducing Shipboard NOx and SOx Emissions on Vessel Performance. Massachusetts Institute of Technology.

GEERTSMA, R., NEGENBORN, R. R., VISSER, K., & HOPMAN, J. J. (2017). Design and control of hybrid power and propulsion systems for smart ships: A review of developments. In Applied Energy (Vol. 194, pp. 30-54). Elsevier Ltd. https://doi.org/10.1016/j.apenergy.2017.02.060

GEERTSMA, R., VOLLBRANDT, J., NEGENBORN, R., VISSER, K., & HOPMAN, H. (2017). A quantitative comparison of hybrid diesel-electricand gas-turbine-electric propulsion for future frigates. Defence Materiel Organisation, 451-458.

HOLTROP, J., & MENNEN, G. G. (1977). An approximate power prediction method. 166-170.

LINDSTAD, H. E., & SANDAAS, I. (2016). Emission and fuel reduction for offshore support vessels through hybrid technology. Journal of Ship Production and Design, 32(4), 195-205. https://doi.org/10.5957/JSPD.32.4.150006

MORALES E., O., SILVA, A., ZÁRATE, F., & ARMADA DE COLOMBIA (2016a). Technical Concept Evaluation of configurations for the ESP propulsion system.

MORALES E., O., SILVA, A., ZÁRATE, F., & ARMADA DE COLOMBIA (2016b). Report Development of evaluation model for selection of the propulsion system of the Strategic Surface Platform - PES.

OHMAYER, H. F. (2012). Propulsion System Choices for modern Naval Vessels.

Royal Navy U.K. (n.d.). DUKE CLASS TYPE 23 FRIGATE. Retrieved January 22, 2023, from https://www.royalnavy.mod.uk/the-equipment/ships/frigates/duke-class

SILATAN, S., EDALAT, P., & RAHIMI, M. (2014). Hybrid Propulsion System For New Generation Of Ships. www.SID.ir

ZHU, J., CHEN, L., WANG, B., & XIA, L. (2018). Optimal design of a hybrid electric propulsive system for an anchor handling tug supply vessel. Applied Energy, 226, 423-436. https://doi.org/10.1016/j.apenergy.2018.05.131.

Editorial Guidelines for Authors

Thematic Interest

The *Ship Science and Technology* Journal accepts for publication original engineering contributions in English language on ship design, hydrodynamics, dynamics of ships, structures and materials, vibrations and noise, technology of ship construction, ocean and marine engineering, standards and regulations, oceanography, maritime and river transport, and port infrastructure, results of scientific and technological researches. Every article shall be subject to consideration of the Editorial Council of The *Ship Science and Technology* Journal deciding on pertinence of its publication.

Typology

The *Ship Science and Technology* Journal accepts to publish articles classified within the following typology (COLCIENCIAS 2006):

- *Scientific and technological research articles*. Documents presenting detailed original results of finished research projects. Generally, the structure used contains four important parts: introduction, methodology, results, and conclusions.
- *Reflection Articles*. Documents presenting results of finished research as of an analytical, interpretative, or critical perspective of the author on a specific theme, resorting to original sources.
- *Revision Articles*. Documents resulting from finished research in the field of science or technology in which published or unpublished results are analyzed, systemized, and integrated to present advances and development trends. These are characterized by presenting an attentive bibliographic revision of at least 50 references.

Format

All articles must be sent to the editor of The *Ship Science and Technology* Journal accompanied by a letter from the authors requesting their publication. Every article must be written in *Microsoft Word* in single space and sent in magnetic form.
Articles must not exceed 10,000 words (9 pages).
File must contain all text and any tabulation and mathematical equations.
All mathematical equations must be written in *Microsoft Word Equation Editor*. This file must contain graphs and figures; additionally, they must be sent in a modifiable format file (soft copy). Also, abbreviations and acronyms have to be defined the first time they appear in the text.

Content

All articles must contain the following elements that must appear in the same order as follows:

Title
It must be concise (no more than 25 words) with appropriate words so as to give readers an idea of the contents of the article. It must be sent in English and Spanish language.

Author and Affiliations
The author's name must be written as follows: last name, initial of first name . Affiliations of author must be specified in the following way and order:

- Business or institution (including department or division to which he/she belongs).
- Street mailing address.
- City (Province/State/Department).
- Country.

Abstract
A short essay of no more than one hundred fifty (150) words, specifying content of the work, scope, and results. It must be written in such a way so as to contain key ideas of the document. It must be sent in English and Spanish language.

Key Words
Identify words and/or phrases (at least three) that recover relevant ideas in an index. They must be sent in English and Spanish language.

Introduction
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.

Body Article
It is made up of the theoretical framework supporting the study, statement of the theme, status of its analysis, results obtained, and conclusions.

Equations, Tables, Charts ang Graphs
All of these elements must be numbered in order of appearance according to their type and must have their corresponding legends, along with the source of the data.

Equations must be numbered on the right hand side of the column containing it, in the same line and in parenthesis. The body of the text must refer to it as "(Equation x)". When the reference starts a sentence it must be made as follows: "Equation x". Equations must be written so that capital letters can be clearly differentiated from lower case letters. Avoid confusions between the letter "l" and the number one or between zero and the lower case letter "o". All sub-indexes, super-indexes, Greek letters, and other symbols must be clearly indicated. All expressions and mathematical analyses must explain all symbols (and unit in which they are measured) that have not been previously defined in the nomenclature. If the work is extremely mathematical by nature, it would be advisable to develop equations and formulas in appendixes instead of including them in the body of the text.

Figure/Fig. (lineal drawings, tables, pictures, figures, etc.) must be numbered according to the order of appearance and should include the number of the graph in parenthesis and a brief description. As with equations, in the body of the text, reference as "(Fig. X)", and when reference to a graph is the beginning of a sentence it must be made as follows: "Fig. x".

Charts, graphs, and illustrations must be sent in modifiable vector file format (*Microsoft Excel, Microsoft Power Period*, and/or *Microsoft Vision*).

Pictures must be sent in TIF or JPG format files, separate from the main document in a resolution higher than 1000 dpi.

Foot Notes
We recommend their use as required to identify additional information. They must be numbered in order of appearance along the text.

Acknowledgment
Acknowledgments may be made to persons or institutions considered to have made important contributions and not mentioned in any other part of the article.

Bibliographic References

The bibliographic references must be included at the end of the article in alphabetical order and shall be identified along the document. To cite references, the Journal uses ISO 690 standards, which specify the mandatory elements to cite references (monographs, serials, chapters, articles, and patents), and ISO 690-2, related to the citation of electronic documents. We also use IEEE standard for the bibliographic references.

ISO 690

Quotations
They must be made in two ways: at the end of the text, in which case the last name of author followed by a comma and year of publication in the following manner:

"Methods exist today by which carbon fibers and prepregs can be recycled, and the resulting recyclate retains up to 90% of the fibers' mechanical properties" (*Davidson, 2006*).

The other way is:

Davidson (2006) manifests that "Methods exist today by which carbon fibers and prepregs can be recycled, and the resulting recyclate retains up to 90% of the fibers' mechanical properties".

List of References
Bibliographic references of original sources for cited material must be cited at the end of the article in alphabetical order and according to the following parameters:

In the event of more than one author, separate by commas and the last one by an "and". If there are more than three authors write the last name and initials of the first author and then the abbreviation "*et al.,*".

Books
Last name of author followed by a comma, initial(s) of name followed by a period, the year of publication of book in parenthesis followed by a comma, title of publication in italics and without quotation marks followed by a comma, city where published followed by a comma, and name of editorial without abbreviations such as Ltd., Inc. or the word "editorial".

Basic Form:
LAST NAME, N.I. *Title of book*. Subordinate responsibility (optional). Edition. Publication (place, publisher). Year. Extent. Series. Notes. Standard Number.

Example:
GOLDBERG, D.E. *Genetic Algorithms for Search, Optimization, and Machine Learning.* Edition 1. Reading, MA: Addison-Wesley. 412 p. 1989. ISBN 0201157675.

If a corporate author
Write complete name of entity and follow the other standards.

Basic form:
INSTITUTION NAME. *Title of publication*. Subordinate responsibility (optional). Edition. Publication (place, publisher). Year. Extent. Series. Notes. Standard Number.

Example:
AMERICAN SOCIETY FOR METALS. *Metals Handbook: Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals*. 9th edition. Asm Intl. December 1980. ISBN: 0871700093.

When book or any publication have as author an entity pertaining to the state, write name of country first.

Basic form:
COUNTRY, ENTITY PERTAINING TO THE STATE. *Title of publication*. Subordinate responsibility (optional). Edition. Publication (place, publisher). Year. Extent. Series. Notes. Standard Number.

Example:
UNITED STATED OF AMERICAN. EPA - U.S. Environmental Protection Agency. Profile of the Shipbuilding and Repair Industry. Washington D.C. 1997. P. 135.

Journal Article

Basic form:
Last name, N.I. Title of article, *Name of publication*. Edition. Year, issue designation, Pagination of the part.

Graduation Work

Basic form:
Primary responsibility. *Title of the invention*. Subordinate responsibility. Notes. Document identifier: Country or issuing office. *Kind of patent document*. Number. Date of publication of cited document.

Example:
CARL ZEISS JENA, VEB. *Anordnung zur lichtelektrischen Erfassung der Mitte eines Lichtfeldes. Et-finder*: W. FEIST, C. WAHNERT, E. FEISTAUER. Int. Cl.3 : GO2 B 27/14. Schweiz Patentschrift, 608 626. 1979-01-15.

Presentation at conferences or academic or scientific event

Basic form:
LAST NAME, N.I. Title of the presentation. In: Sponsor of the event. *Name of the event*. Country, City: Publisher, year. Pagination of the part.

Example:
VALENCIA, R., et al. Simulation of the thrust forces of a ROV En: COTECMAR. P*rimer Congreso Internacional de Diseño e Ingeniería Naval CIDIN 09*. Colombia, Cartagena: COTECMAR, 2009.

Internet

Basic form:
[1] LAST NAME, N.I. *Title of work*, [on-line]. Available at: http://www.direccion_completa.com, recovered: day of month of year.

Example:
[1] COLOMBIA. ARMADA NACIONAL. COTECMAR gana premio nacional científico, [web on-line]. Available at: http://www.armada.mil.co/?idcategoria=545965, recovered: 5 January of 2010.

IEEE

IEEE Publications uses Webster's College Dictionary, 4th Edition. For guidance on grammar and usage not included in this manual, please consult The Chicago Manual of Style, published by the University of Chicago Press.

Books

Basic form:
[1] J. K. Author, "Title of chapter in the book," in *Title of His Published Book*, *x*th ed. City of Publisher, Country if not USA: Abbrev. of Publisher, year, ch. *x*, sec. *x*, pp. *xxx–xxx*.

Example:
[1] B. Klaus and P. Horn, *Robot Vision*. Cambridge, MA: MIT Press, 1986.

Handbooks

Basic form:
[1] *Name of Manual/Handbook*, *x* ed., Abbrev. Name of Co., City of Co., Abbrev. State, year, pp. *xx-xx*.

Example:
[1] *Transmission Systems for Communications*, 3rd ed., Western Electric Co., Winston-Salem, NC, 1985, pp. 44–60.

Reports
The general form for citing technical reports is to place the name and location of the company or institution after the author and title and to give the report number and date at the end of the reference.

Basic form:
[1] J. K. Author, "Title of report," Abbrev. Name of Co., City of Co., Abbrev. State, Rep. *xxx*, year.

Example:
[1] E. E. Reber *et al.*, "Oxygen absorption in the earth's atmosphere," Aerospace Corp., Los Angeles, CA, Tech. Rep. Angeles, CA, Tech. Rep. TR-0200 (4230-46)-3, Nov. 1988.

Conference Technical Articles
The general form for citing technical articles published in conference proceedings is to list the author/s and title of the paper, followed by the name (and location, if given) of the conference

publication in italics using these standard abbreviations. Write out all the remaining words, but omit most articles and prepositions like "of the" and "on." That is, *Proceedings of the 1996 Robotics and Automation Conference* becomes *Proc. 1996 Robotics and Automation Conf.*

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

For an electronic conference article when there are no page numbers:
[1] J. K. Author [two authors: J. K. Author and A. N. Writer] [three or more authors: J. K. Author et al.], "Title of Article," in [Title of Conf. Record as it appears on the copyright page], [copyright year] © [IEEE or applicable copyright holder of the Conference Record]. doi: [DOI number]

For an unpublished papr presented at a conference:
[1] J. K. Author, "Title of paper," presented at the Unabbrev. Name of Conf., City of Conf., Abbrev. State, year.

Online Sources

The basic guideline for citing online sources is to follow the standard citation for the source given previously and add the Digital Object Identifier (DOI) at the end of the citation, or add the DOI in place of page numbers if the source is not paginated. The DOI for each IEEE conference article is assigned when the article is processed for inclusion in the IEEE Xplore digital library and is included with the reference data of the article in Xplore. See The DOI System for more information about the benefits of DOI referencing.

The following sources are unique in that they are electronic only sources.

FTP

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

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

WWW

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

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

E-Mail

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

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

E-Mail

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

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

Patents

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

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

Standards

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

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

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

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

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

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

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

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

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

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

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

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

References in Text:
References need not be cited in the text. When they are, they appear on the line, in square brackets, inside the punctuation. Grammatically, they may be treated as if they were footnote numbers, e.g.,
as shown by Brown [4], [5]; as mentioned earlier [2], [4]–[7], [9]; Smith [4] and Brown and Jones [5]; Wood et al. [7]
or as nouns:
as demonstrated in [3]; according to [4] and [6]–[9].

References Within a Reference:
Check the reference list for ibid. or op. cit. These refer to a previous reference and should be eliminated from the reference section. In text, repeat the earlier reference number and renumber the reference section accordingly. If the ibid. gives a new page number, or other information, use the following forms:
[3, Th. 1]; [3, Lemma 2]; [3, pp. 5-10]; [3, eq. (2)]; [3, Fig. 1]; [3, Appendix I]; [3, Sec. 4.5]; [3, Ch. 2, pp. 5-10]; [3, Algorithm 5].

NOTE: Editing of references may entail careful renumbering of references, as well as the citations in text.

Acceptance

Articles must be sent by e-mail to the editor of The *Ship Science and Technology* Journal to otascon@cotecmar.com or in CD to the journal's street mailing address (COTECMAR Mamonal Km 9 Cartagena Colombia), accompanied by the "Declaration of Originality of Written Work "included in this journal.

The author shall receive acknowledgement of receipt by e-mail. All articles will be submitted to Peer Review. Comments and evaluations made by the journal shall be kept confidential. Receipt of articles by The Ship Science and Technology

Journal does not necessarily constitute acceptance for publishing. If an article is not accepted it shall be returned to the respective author. The Journal only publishes one article per author in the same number of the magazine.

Opinions and declarations stated by authors in articles are of their exclusive responsibility and not of the journal. Acceptance of articles grants The Ship Science and Technology Journal the right to print and reproduce these; nevertheless, any reasonable petition by an author to obtain permission to reproduce his/her contributions shall be considered.

Further information can be obtained by:
Sending an e-mail to sst.journal@cotecmar.com
Contacting Carlos Eduardo Gil De los Rios (Editor)
The Ship Science and Technology (Ciencia y Tecnología de Buques) office located at:
COTECMAR Bocagrande Carrera 2da Base Naval A.R.C. Bolívar
Cartagena de Indias – Colombia.
Phone Number: +57 (5) 653 5511

SHIP
SCIENCE & TECHNOLOGY
CIENCIA & TECNOLOGÍA DE BUQUES

Statement of Originality of Written Work

Title of work submitted

____

____

I hereby certify that the work submitted for publication in The Ship Science and Technology journal of Science and Technology for the Development of Naval, Maritime, and Riverine Industry Corporation, COTECMAR, was written by me, given that its content is the product of my direct intellectual contribution. All data and references to material already published are duly identified with their respective credits and are included in the bibliographic notes and quotations highlighted as such.

I, therefore, declare that all materials submitted for publication are completely free of copyrights; consequently, I accept responsibility for any lawsuit or claim related with Intellectual Property Rights thereof.

In the event that the article is chosen for publication by The Ship Science and Technology journal, I hereby state that I totally transfer publication and reproduction rights of such to the Science and Technology Corporation for the Development of Naval, Maritime, and Riverine Industry - COTECMAR, which will be simultaneously subject to the Creative Commons Attribution License (CC -BY) that allows the license to copy, distribute, display and represent the work and to make derivative works as long as it recognizes and cites the work in the manner specified by the author or licensor, without territorial limitation.

This assignment of rights does not obligate Cotecmar to pay for the article and in retribution of it I agree to receive two issues of the journal number where my article is published.

In witness thereof, I sign this statement on the ______ day of the month of _______________ of year ______________, in the city of _______________ .

Name and signature:

____

Identification document:

____

Level of Education:

____

Institutional Affiliation:

____

COTECMAR
COLOMBIA

Km. 9 Vía Mamonal - Cartagena, Colombia
www.shipjournal.co

Vol. 17 - N.° 34

January 2024

COTECMAR

www.shipjournal.co