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# Editorial Note

Cartagena de Indias, July $21^{nd}$, 2016

During the first semester of 2016, COTECMAR continues the development of its investigation projects portfolio, technology development and innovation aimed to positioning new technology and knowledge within national and international scope. The dynamic of Strategic Surface Platform program – (PES by its Spanish initials), which is turning into a productive transformation program in Colombia, is performing as an integrator within naval sector and its ancillary industry; COTECMAR is also making 100% of the Offshore Patrol Vessel design, and will participate again in the new Antarctica expedition in order to maintain new material research and other interest topics for naval industry. From international perspective, the corporation has two projects of codevelopment and technology transfer in progress, one is Naval tactical Datalink in Chile and the other is the Amazonic Patrol Vessel with the cooperation of Brazil and Peru.

This year, one of the corporation's challenges is the design, construction and placing on market of new products for post-conflict in Colombia, for this reason it is working now under dual technology approach by turning this defense technology into products for the society use that reach a high economic and social impact in different regions and national communities.

Moreover, the corporation maintains the science and technology diffusion and social appropriation as a main purpose that allows sharing and transferring knowledge through Ship Science and Technology Journal and the International ship design and naval engineering congress, which its fifth version will take place from March $15^{th}$ to March $17^{th}$ of 2017 in Cartagena City, remaining as one of the most important events in naval architecture and engineering and other related topics for shipyard industry.

In this edition we present research related to floating city, waste reduction cutting using a genetic algorithm, analysis of the reliability of a naval tactical Data Link, analysis of operational and seakeeping aspects in the design of PSV type for the colombian caribbean sea and structural design of a jacket platform.

We thank to our authors and readers, who belong to naval scientific community, that allow us giving and sharing the results of research and knowledge through our Ship Science and Technology Journal.

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

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# Nota Editorial

Cartagena de Indias, 21 de julio de 2016.

Durante el primer semestre del año 2016, Cotecmar continua con el desarrollo de su portafolio de proyectos en investigación, desarrollo tecnológico e innovación orientados a posicionar nuevas tecnológicas y conocimiento en el ámbito nacional e internacional. La dinámica del programa Plataforma Estratégica de Superficie – PES se torna hacia un programa de transformación productiva en Colombia; siendo el articulador del sector naval y sus industrias conexas, se gesta el nuevo diseño 100% Colombiano de una Patrullera Oceánica (Offshore Patrol Vessel), y se participará nuevamente en la expedición Antártica para continuar con las investigaciones asociadas a nuevos materiales y temáticas de interés para la industria naval. Desde la perspectiva internacional se tienen dos proyectos de codesarrollo y transferencia tecnológica en marcha, Sistema de Red Táctica Naval con Chile y la Patrullera Amazónica con Brasil y Perú.

Este año, uno de los nuevos retos que ha asumido la Corporación es el diseño, construcción y puesta en el mercado de nuevos productos para el postconflicto en Colombia, es por ello que actualmente se trabaja bajo el enfoque de tecnología dual transformando aquellas tecnologías de defensa en productos para uso de la sociedad, que logren tener un alto impacto económico y social en las regiones y en la comunidad nacional.

Continuando además, con la divulgación y apropiación social de la ciencia y la tecnología, propósito corporativo que nos permite compartir y transferir conocimientos a través de la Revista Ciencia y Tecnología de Buques, y del Congreso Internacional de Diseño e Ingeniería Naval, esté último que llegará a su quinta versión del 15 al 17 de Marzo de 2017 en la ciudad de Cartagena, como uno de los principales eventos de divulgación científica de la región especializado en ingeniería, arquitectura naval y otros temas afines a la industria astillera.

En esta edición les presentamos investigaciones relacionadas con: Ciudad flotante, reducción de desperdicios en corte de figuras rectangulares usando algoritmo genético, incremento en la fiabilidad de un enlace táctico naval, análisis de los aspectos operacionales y de comportamiento en olas en el diseño de embarcaciones de apoyo tipo PSV para el caribe colombiano y análisis estructural de una plataforma fija tipo Jacket con aplicación al caribe colombiano.

A todos nuestros autores y lectores, agradecimientos por formar parte de la comunidad científica naval permitiéndonos difundir y dar a conocer los resultados de investigación y conocimientos a través de nuestra Revista Ciencia y Tecnología de Buques.

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

# Seasted Floating City. Innovative Development of a New City Model

Seasted: Ciudad Flotante Desarrollo innovador para un nuevo modelo de ciudad

Lina K. Suárez [1]

## Abstract

Seastead is a floating city experiment for international waters based on economic studies carried out by the Seasteading Institute, which seeks to increase real estate market growth, driven by an economic incentive dedicated to medical tourism, aquaculture, technology incubators, and support platforms for offshore rigs. A new pre-conceptual model of a floating city was created, conceptualizing an analysis of the floating habitat as a means for development and expansion. This new habitat style was designed taking into account considerations of the marine habitat, current habitats, utopian projects and studies regarding the expansion of urban spaces. The city was designed on a semi-submersible offshore platform chosen through a parametric model made by the Seasteading Institute, which allowed for a final modular array comprised by 300 containers organized by a crane system, this being the organizational system of the city.

**Key words:** Floating city, future cities, floating habitat, innovation.

## Resumen

Seasted presenta el experimento de una ciudad flotante en aguas internacionales con base en estudios realizados por el instituto Seasteading, el cual busca incrementar el crecimiento de mercado en bienes raíces, conducido por un incentivo económico dedicado al turismo médico, acuicultura, incubadoras de tecnología y apoyo para las plataformas de perforación costa afuera. Un nuevo modelo pre-conceptual de ciudad flotante fue creado, conceptualizando un análisis de hábitat flotante como medio de desarrollo y expansión. Este nuevo estilo de entorno habitacional fue diseñado teniendo en cuenta consideraciones del ambiente marino, hábitat actual, estudios utópicos y estudios referentes a expansión de espacios urbanos. La ciudad fue diseñada en una plataforma semi-sumergible costa afuera elegida a través de un modelo paramétrico realizado por el instituto Seasteding, el cual permitió una formación modular final compuesta por 300 contenedores organizado por un sistema de grúas, siendo este el sistema organizacional de la ciudad.

**Palabras claves:** Ciudad flotante, ciudades del futuro, hábitat, innovación.

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## Introduction

This document seeks to inform about the methodology used in the process of developing a floating city that could resemble the sustainable city model and suitable for various uses on international waters.

This work was developed based on a report of the DPEA of Naval Architecture of Nantes, which focused on the analysis of the state of the art in floating habitats worldwide, analyzing options for lasting and thriving economic growth, on the basis of on-water architecture, mainly considering worldwide social concerns and innovation opportunities in an innovative manner. Initially, activities performed since the Middle Ages up to present day were identified, showing that water is useful for power generation, transport, and tourism among others, reason for undertaking the development of a vanguard floating habitat model. Meanwhile, in California, Seasteading was in charge of producing a concept for permanent housing at sea, which is not ruled by any country, created on the basis of an economic model seeking to facilitate establishing autonomous floating communities on marine platforms operating in international waters.

The merger of these two studies enabled the materialization of the modular floating Seastead city, which started being developed on an offshore platform that had to be strategically located close to Silicon Valley, 200 NM off the east coast of the United States.

Development started by taking into account the various types of missions that may be undertaken by the same model, which should allow multipurpose functions of the platform, such as a technology incubator (software development), medical tourism (experimental medical treatments), aquaculture or fish farming, OTEC (Ocean Thermal Energy Conversion), resort, offshore casino, among other similar purposes.

A design methodology was developed which enabled the conceptual development of an autonomous modular floating city that allows innovation of new social policies and systems. This is part of a Seasteading research project that is currently seeking development under the "The Foating City Project", which can be found on the following website: http://floating-city.org.

## Background

The floating habitat has created a signature lifestyle in the communities and times where it has been built, providing commercial, urban, artisan, utopian and even fantastic developments such as Jules Verne described in L'Ile a hélice « qui sait si la terre ne sera pas trop petite un jour pour ses habitants dont le nombre doit atteindre six millards en 2072…et ne faudra t-il pas bâtir sur la mer, alors que les continents seront encombres? ».

Various habitats have been created throughout the years, some out of necessity, adaptation to the environment, luxury, exclusiveness, urbanistic studies, creation of new communities, or simply for the creation of micro-nations in the world.

Since 1359, in Lake Inle in Burma, Asia, wooden and bamboo houses were built on piles that are still standing, due to their geographical location, crops and houses are placed above water. Thai and Vietnamese cultures also have great development in lacustrine villages, one of them in the Andaman Sea, which holds maritime nomadic people known as « Moken », or sea gypsies, who preserve their sea-based ancestral culture; Zhouzhuang, created in 770 B.C. It preserves ancient houses and bridges, and it is thus recognized as the #1 water community in China, holding a UNESCO World Heritage designation[1].

In Europe, between the Neolithic and the Bronze Ages (4300 to 800 A.C.), the Swiss lacustrine villages were populated by the littoral prehistoric groups. Currently, due to expansion, Holland has urban development projects, residential and commercial constructions above water. During the Middle Ages, bridges were used as commercial galleries and residences, such as the still preserved

[1] http://whc.unesco.org/en/tentativelists/5328/

Pont Vecchio in Florence, built between 1335 and 1345, or the old London Bridge, built in 1745, or the Hotel Dieu bridge, massively built in 1499; cities such as Venice, which was built on the lagoon sand and supported on thousands of wooden piles; and micro nations such as today's Sealand appeared, which established on a military platform in 1967, and currently lodges only 5 people and is proclaimed as an independent territory[2].

In Africa, the Ganvie village located in Lake Nokoue, Benin, was established between XVI and VXII, and holds one of the largest African populations living in a lake It is recognized by the water-based activities performed by its people, and is currently a tourism hotspot.

There is a Latin American indigenous group, the Uros, a pre-Inca people that live on 42 self-fashioned floating islands in Lake Titicaca; this group weaves their temporary islands for their homes with totora, which demands a new layer every two weeks to prevent the islands from sinking[3]; in 1325, Tenochtitlan was built on an island in lake Texcoco, as capital of the Mexican empire.

Based on the ideal world of the 60s and 70s, countless utopian floating cities were created, such as Kisho Kurokawa's Helix for Kasumigaura, Japan, in 1961, which is developed into mega spirals based on the DNA[4] structure; the Urban Matrix or Flattions Resort Complex by Stanley Tigerman in 1967 and 1972, respectively, sought to extend a metropolis on an aluminum lightweight structure shaped as a tetrahedron to generate less resistance to the marine elements. Projects linked to the Tokyo bay development by Paul Maymont in 1959 and Kenzo Tange in 1961 were aimed at generating spaces for me city's overpopulation; the Lingang New City, developed by GMP in Shanghai sought an economic, commercial, and financial megapolis to support the Shanghai business hub; the modular Floating City created by Craven and Kikutake in 1970 was developed to reduce congestion in Honolulu. Even an amphibious city was conceived by Lacroix-Verdeaux in 1971, dedicated to maritime relaxation as an amphibious vacation site.

Considering the various issues identified and the favorable arguments to address the development of a multifunctional floating structure, the search for the development of aquatic projects that will allow improvement for the current living conditions, and as a consequence, the development of an individual and collective habitat defined on the basis of a physical and moral condition that addresses the psychological and physiological needs of the 21st century mankind.

## Development process

"The Laws on the water are different from those on land" [5]

We made first contact with Seasteading, which has been on a 5-year search of a solution to social issues, from the baseline of a permanent research process for the innovative development of offshore floating communities, which has explored waste disposal all the way through coexistence halls.

Seasteading decided to develop floating cities in international waters taking advantage of the "freedom of the high seas"[6], which is established in the United Nations Convention on the Law of the Sea under Article 87, with the purpose of using the ultimate non-claimed territory on earth, which therefore is not subject to any regulation, allowing personal freedom, experimenting on a new social, political and economic system.

## Development

The following procedure was used to develop the platform:

- Identification of requirements
- Study of design constraints
- Typological volume definition
- Internal functional analysis

[2] http://www.sealandgov.org
[3] http://punoperu.orige nandino.com/isla-de-los-uros.html
[4] http://www.kisho.co.jp/page.php/200

[5] K. Olthuis y D. Keuning. Float! Building on water to combat urban congestion. Pag, 239. 2011.
[6] http://floating-city.org/

- Reconfiguration
- Design of dwelling types

## Identification of requirements

Development of a sustainable, legal, and technological aquatic civilization was proposed on a 300x300’ offshore platform, comprised by a pontoon, four columns and a semisubmersible ring selected by Seasteading after a parametric analysis created to configure floating platforms and designed under the main requirements defined by the Institute.

Table 1. Main requirements.

| | |
|---|---|
| **Functional requirements** | |
| Accommodation | 400 people in 300 $ft^2$, approx. |
| | 75% people in 600$ft^2$ units for 2 persons |
| | 25% people in 900 to 1200 $ft^2$ for 3 or 4 persons |
| | 40 guests in 120 to 180 $ft^2$ spaces per person |
| | 10 luggage in single private spaces |
| Public areas | 2 levels combining an inner area of less than 100,000 $ft^2$ |
| Service areas | Front desk |
| Commercial spaces | Stores |
| | Supermarket |
| | Coffee shops and restaurants |
| **Structural requirement** | |
| Static load | > 94 lb./ $ft^2$ inner spaces |
| | Consider ice, snow, or water accumulation on decks |
| **Habilitation/enabling and safety requirements** | |
| | Sikorsky-61 helicopter accommodation |
| | Fire code compliance, fire alarms |
| | Command and control bridge |
| | Vessel docking platform and recreational space |

## Design constraints

Once the platform requirements and dimensions were known, the offshore implantation site was analyzed, using information provided by a NOAA (National Oceanic and Atmospheric Administration) buoy named station 46059 located at 357 NM west of San Francisco, coordinates 38°2'49" N 129°58'8" W. The data shown in Table 2 corresponds to these coordinates, which was considered in the design of the platform superstructure.

Table 2. Main requirements.

| | | | |
|---|---|---|---|
| Wind speed | Max | 45 | kn |
| | Average | 7 to 22 | kn |
| Air Temperature | Max | 22 | °C |
| | Min | 5 | °C |
| | Average | 10 to 19 | °C |
| Sea Temperature | Max | 21 | °C |
| | Min | 10 | °C |
| | Average | 11.5 to 19.5 | °C |
| Wave height | Max | 14 | m |
| | Average | 2.5 to 5.5 | m |
| Wave period | Max | 15.5 | s |
| | Average | 5.5 to 9.5 | s |

Considering that the parameters of the semisubmersible offshore platform provided for the development of this city had been studied and thus selected, developing the superstructure was the most important process.

## Typological definition

Upon identification of the location conditions, requirements, worldwide references in floating city design, usage of green technologies, among others, a process of functional and aesthetic volumetric location began, to meet the ideal neighborhood or city that the people of Seastead would pursuit.

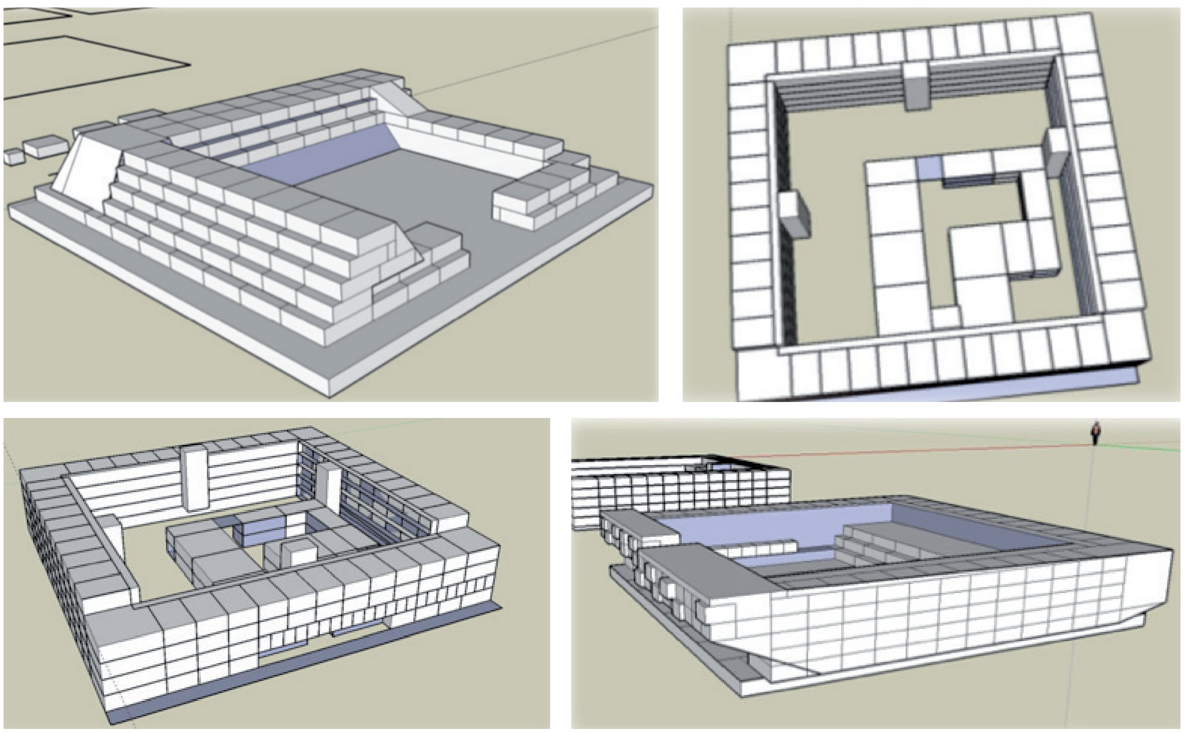
Taking into account that the only means of transportation to reach it are by sea or air, that the recreation sites should be related to the sea and air, that housing should be modular and ephemeral, that workspaces should be suited to the characteristics of the desired business and that social issues depend on the new open social system a typological definition to achieve the purpose of the city, which allows for economical growth, increase in quality of life, higher social and cultural justifications and new entrepreneurial models had to be developed.

Models were developed for the Seasteading mini-city aimed at defining space requirements for human development, considering their physical well-being and their social needs, stressing on the mixed uses in one same platform, given its small dimensions.

Each model considered a suitable allocation of areas and sub-areas to foster normal life cycles, holding homes (private), a work or education space (demi-private), and a socialization space (public). Each one of these spaces meets international standards for a person's habitation and development.

As the volumetric analysis of each one of these proposals was completed, prioritization elements of the models were identified, such as weight analysis, sustainable system alternatives, stability analysis and dwelling area design.

Fig. 1. Typological definition options.



## Internal functional analysis

A typological model was selected to be analyzed from the functional standpoint to meet each function of a sustainable city. Locating residential areas, work areas, commercial areas, circulation, hotel area, technical area, and central recreational spaces in terraces, the middle area of the platform with a direct connection to the ocean.

Fig. 2 shows one of the latest functional analysis performed to define the final model, displaying its external structure in Fig. 3.

## Reconfiguration

After a few months of analysis, the Seasteading Institute, requested a new superstructure model only using containers in order to reduce the cost of the platform and to enable its consolidation process.

A similar design process was undertaken, using the same location, performance specifications and design restrictions previously identified. After a long analysis the main hubs of the platform were determined to be cranes that would allow arranging the containers in the Seastead city, and therefore several arrays such as the ones shown in Fig. 4 were prepared.

## Dwelling type design

Considering the crane as the main hub for the volumetric organization, it was conceived as the connection point for each container, suggesting a connection of the utilities supplied by the platform for these ephemeral dwellings.

The idea is that people interested in trying out living in a floating city to develop new businesses, may connect and disconnect, generating movement and an extended use of the dwelling modules.

With this purpose, 60 fixed containers and 240 mobile containers were crafted, all with the option for any of the configurations proposed in Figs. 5, 6, and 7.

Fig. 2. Internal Functional Analysis.

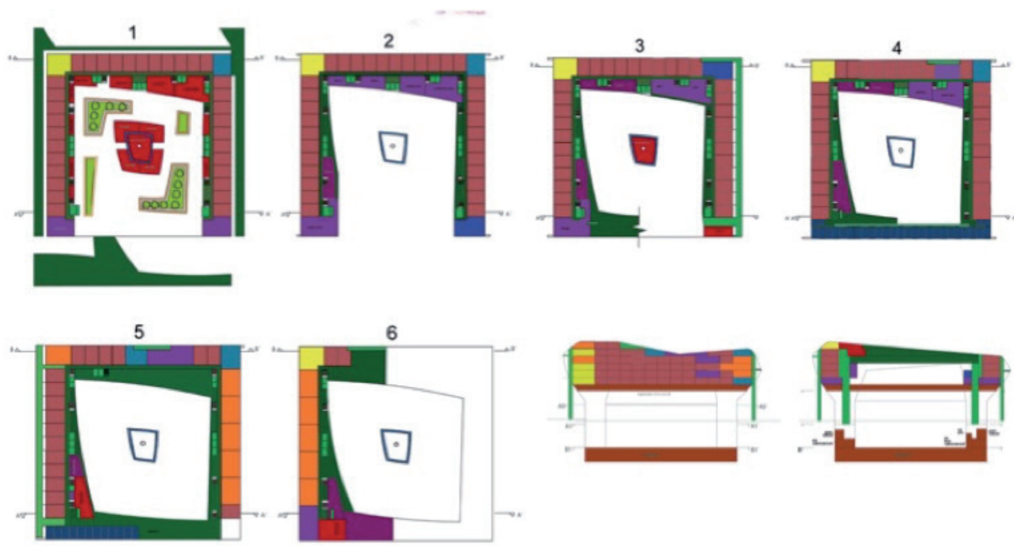



Fig. 3. External Artistic View.

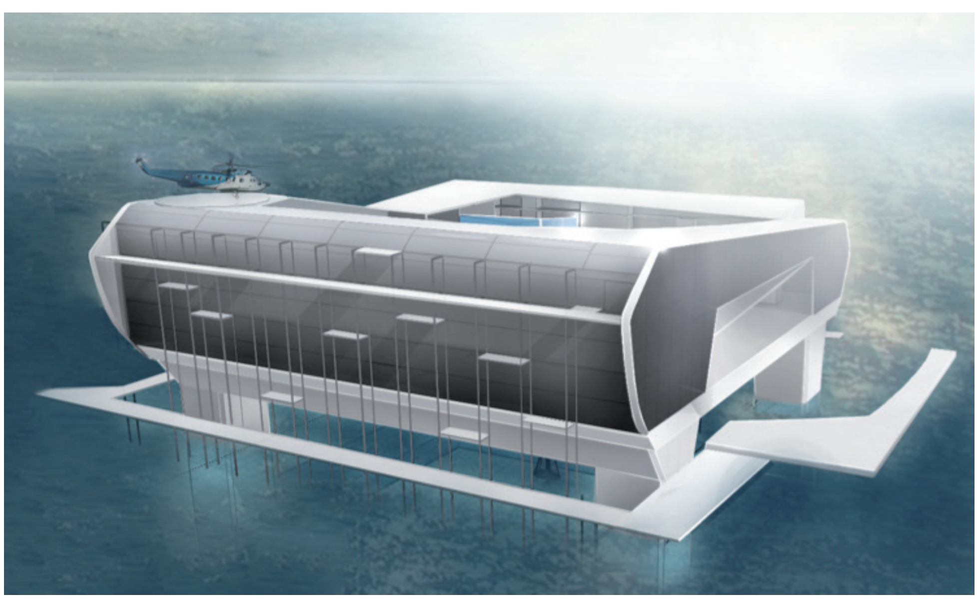


Fig. 4. Container type array.

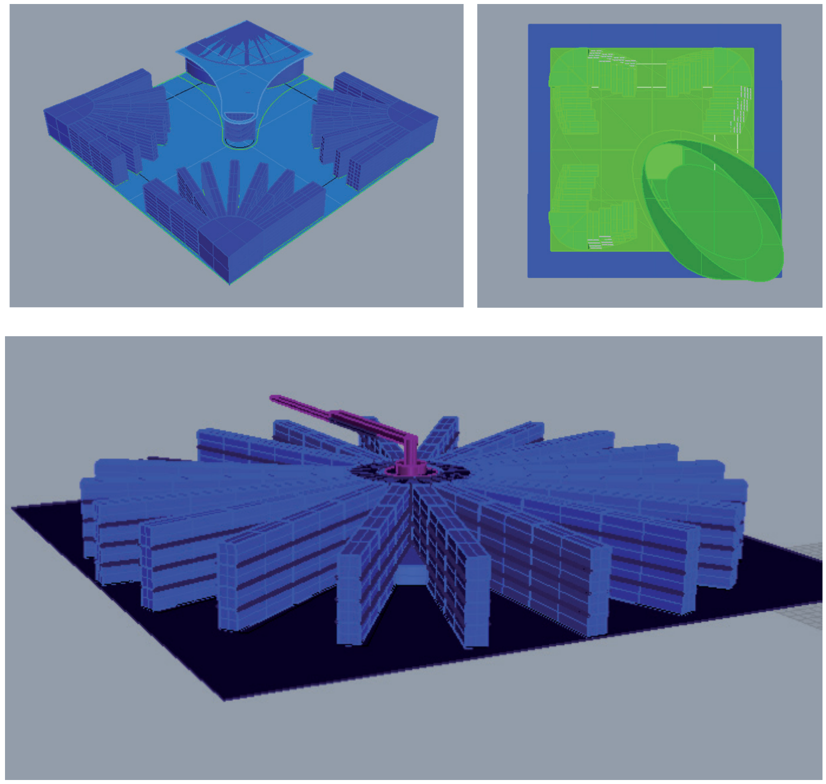


Fig. 5. Type 1 simple model.

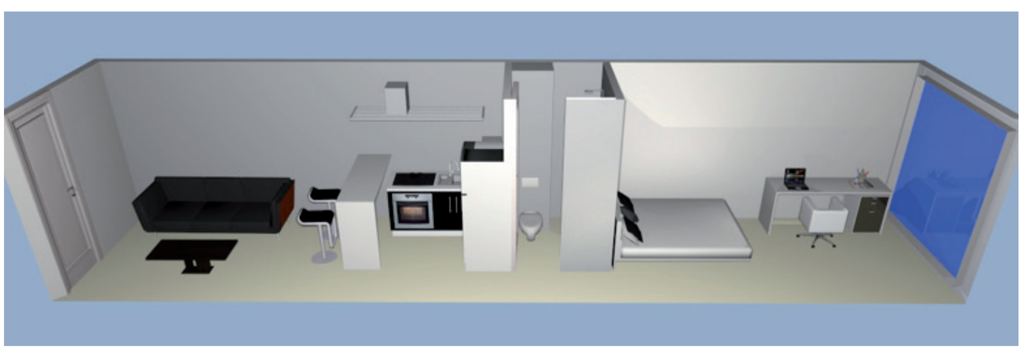


Fig. 6. Type 2 simple model.

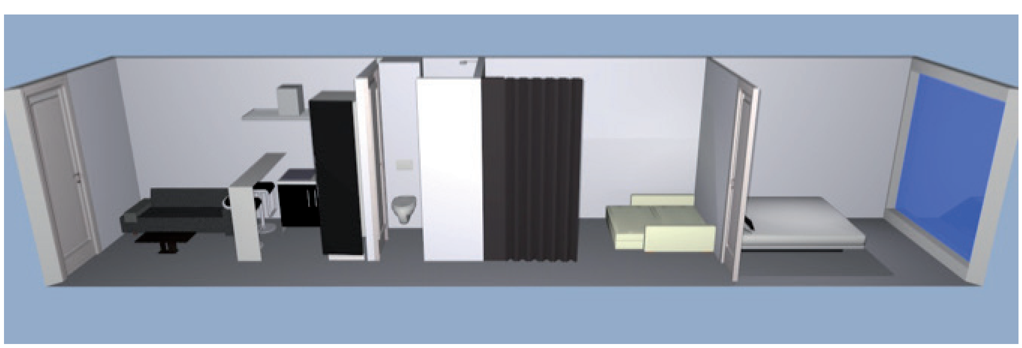


Fig. 7. Type 3 dual model.

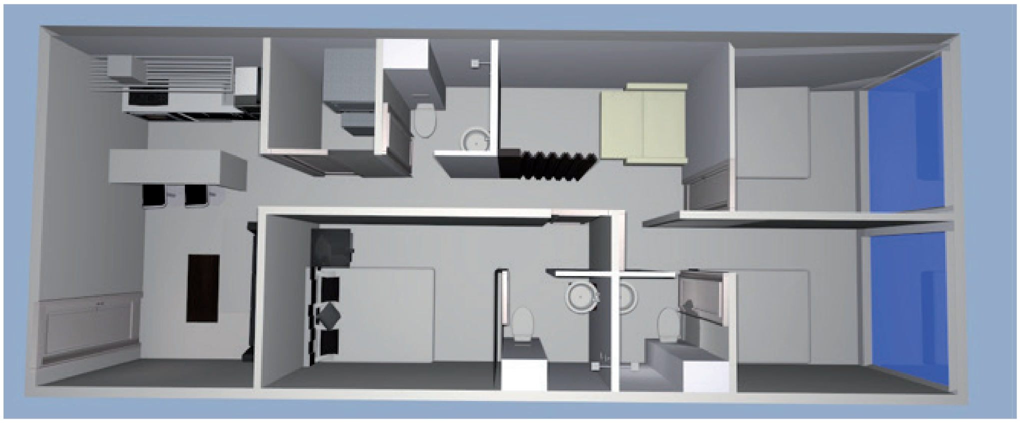
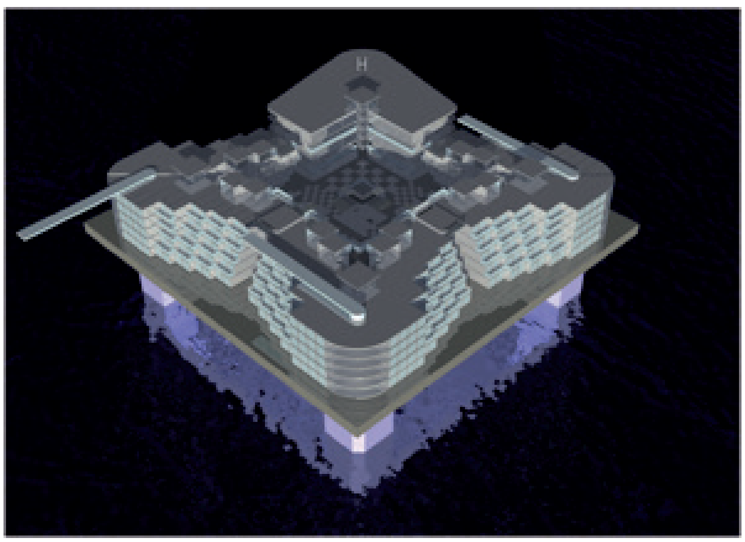


Fig. 7. Type 3 dual model.



The superstructure for a platform was designed with the following characteristics:

| | |
|---|---|
| LWL | 77.4 meters (245 ft) |
| BwL | 20.6 meters (67.8 ft) |
| Maximum draught | 21.3 meters (70 ft) |
| Depth | 60.9 meters (200 ft) |
| Displacement | 26 150 Tons |
| # of containers | 300 |

We found that the development of cities such as Seastead has many functional demands due to the need for psychological and physiological compliance in a sustainable and innovative space, arising from the need for innovation and product services, and/or procedure development for successful applications, where knowledge through creativity and vanguard prevails. Implementing new concepts, therefore, promotes process creation, production, and transformation.

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# Waste reduction in Rectangular Figure Cutting using a Genetic Algorithm

Reducción de desperdicios en corte de figuras rectangulares usando algoritmo genético

Juan C. Rodríguez Noriega [1]
Jairo R. Coronado-Hernández [2]
Sergio Leottau [3]

## Abstract

This paper introduces a genetic algorithm (GA) to minimize the waste produced during the cutting process of rectangular figures on a sheet. The chromosomes for solution codification use an object-based representation. It has the following operator: Partially Mapped Crossover (PMX), mutation based in double interchange (2-opt), and the elitism strategy for the selection process. The proposed algorithm was applied in a real case situation problem, where the numbers of items were 55 pieces. The result of this implementation was a reduction of the waste as a result of the decrease in the number of sheets used in the cutting process and at the same time an effective employment of the used area.

**Key words:** Genetic Algorithm, bin packing problem, metaheuristic.

## Resumen

Este artículo presenta un algoritmo genético para minimizar el desperdicio producido durante el proceso de corte de figuras rectangulares en una lámina. Los cromosomas para la codificación de la solución usan una representación basada en objetivos. Este tiene el siguiente operador: Mapa de cruce por emparejamiento parcial (PMX), mutación basada en el doble intercambio (2-opc) y la estrategia de elitismo para el proceso de selección. El algoritmo propuesto fue aplicado en una situación problema de un caso real, donde el número de ítems eran 55 piezas. El resultado de esta implementación fue la reducción de desperdicio como resultado de la disminución del número de láminas usadas en los proceso de corte y al mismo tiempo el empleo efectivo del área usada.

**Palabras claves:** Algoritmo genético, problema de empaquetado, metaheurística.

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## Introduction

This document presents a genetic algorithm (GA) to minimize the waste produced when cutting rectangular figures out of a sheet. In academic literature, this problem is known as the Bin Packing Problem – BPP. The problem consists in searching for the best possible distribution in a sheet format or a predetermined plate, given a set of pieces with different shapes.

Several types of industries require tools to solve this issue, that may be applied to cutting materials such as metal, wood, glass, plastic, paper, leather, among others. For example, it is a common problem in the shipbuilding industry, since rectangular shapes are cut out of metal sheets and then used to join flat and curved blocks in order to assemble vessels. There are three types of packing problems in literature: two-dimensional bin packing problem (2D-BPP); two dimensional cutting stock problem (2D-CSP); and two-dimensional strip packing problem (2D-SPP). This effort addresses the 2D-BPP problem.

This document introduces a genetic algorithm (GA) to solve the problem of cutting rectangular pieces in a rectangular area.

Binkley & Hagiwara, 2006, describe the packing issue through the four corner heuristics with an auto-adaptive genetic algorithm to find the best solution to the problem. Lee, 2008, suggests a GA a crossover operator that will enable generating several offspring from a couple of parents. Albano & Sappuro, 1980 show one of the first researches related to the problem, accepting regular or irregular-shaped pieces; it uses a heuristic as a solution-seeking method.

## Methodology

### Definition of the Problem

The mathematical problem is shown in Álvarez & Toro, 2009; annex 1 where the model parameters and variables are presented. Equation (1) shows the target function which consists of minimizing the amount of wasted material. Equations (2) to (5) avoid superimposing rectangles on the sheet. Equation (6) ensures that the couple of rectangles assessed with the above equations fit within the dimensions of the sheet. Equations (7) and (8) ensure that the positions of the pieces fit within the sheet dimensions

$$Min\ L.W - \sum_{i=1}^{N} p_i \cdot q_i \cdot s_i \tag{1}$$

Sujeto a:

$$x_i + p_i \cdot l_{xi} + q_i \cdot w_{xi} \leq x_k + (1 - a_{ik}) * M, \quad \forall i, k, i < k \tag{2}$$

$$x_k + p_k \cdot l_{xk} + q_k \cdot w_{xk} \leq x_i + (1 - b_{ik}) * M, \quad \forall i, k, i < k \tag{3}$$

$$y_i + p_i \cdot l_{yi} + q_i \cdot w_{yi} \leq y_k + (1 - c_{ik}) * M, \quad \forall i, k, i < k \tag{4}$$

$$y_k + p_k \cdot l_{yk} + q_k \cdot w_{yk} \leq y_i + (1 - d_{ik}) * M, \quad \forall i, k, i < k \tag{5}$$

$$a_{ik} + b_{ik} + c_{ik} + d_{ik} \geq s_i + s_k - 1, \forall i, k, i < k \tag{6}$$

$$x_i + p_i \cdot l_{xi} + q_i \cdot w_{xi} \leq L + (1 - s_i) * M, \quad \forall i \tag{7}$$

$$y_i + p_i \cdot l_{yi} + q_i \cdot w_{yi} \leq W + (1 - s_i) * M, \quad \forall i \tag{8}$$

$$x_i + p_i \leq x_k + (1 - a_{ik}) * M, \quad \forall i, k, i < k \tag{9}$$

$$x_k + p_k \leq x_i + (1 - b_{ik}) * M, \quad \forall i, k, i < k \tag{10}$$

$$y_i + q_i \leq y_k + (1 - c_{ik}) * M, \quad \forall i, k, i < k \tag{11}$$

$$y_k + q_k \leq y_i + (1 - d_{ik}) * M, \quad \forall i, k, i < k \tag{12}$$

$$x_i + p_i + q_i \leq L + (1 - s_i) * M, \quad \forall i \tag{13}$$

$$y_i + p_i + q_i \leq W + (1 - s_i) * M, \quad \forall i \tag{14}$$

Packing problem models without piece rotation are obtained by replacing equations (2) to (8) for equations (9) to (14), respectively.

### Genetic Algorithm Design

To solve the problem, most procedures reported in literature are based on metaheuristic techniques *(Álvarez & Toro, 2009)*. Therefore, this paper addresses the problem from the genetic algorithm implementation standpoint.

Individual representation was based on objects *(Lee, 2008)* as a solution coding mechanism; this is due to the easy implementation of genetic operators. Object based coding consists of a swap of the given pieces. The values for each gene represent the pieces, whereas the sub index is only useful to indicate the packing order on the sheets, e.g.: given the following chromosome 3 2 4 5 6 1, Fig. 1 shows that pieces 3,2 are cut out of sheet 1, pieces 4, 5 are cut out of sheet 2, and pieces 6, 1, are cut out of sheet 3.

Fig. 1. Object or piece-based representation.

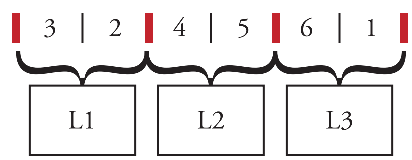
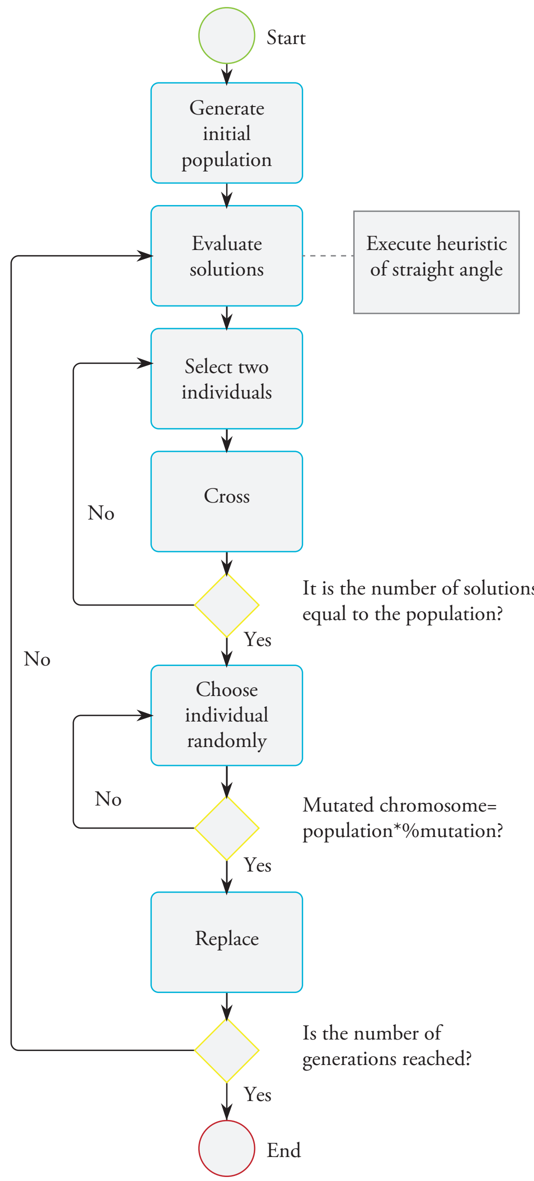



Fig. 1 shows the structure of the genetic algorithm used to solve the problem.

The starting population is generated at random, using right angle polygon heuristics (Bottom Left) proposed in *(Jakobs, 1996)*. This heuristics is used to define the way in which the pieces will be cut out of the sheet and therefore, defines the adaptation for each individual with the fitness function calculated as $F=\sum_{i=1}^{m}\sum_{j=1}^{n}(A_i-t_j)$ . Where $A_i$ is the area of the sheet $i$, and tj is the area of piece $j$ packed in sheet i. In this case, the area of the last sheet is considered to be calculated with the height of the piece that stands out the most from the rest of the pack, which is known as maximum height.

Fig. 2. Flow chart of the proposed genetic algorithm.

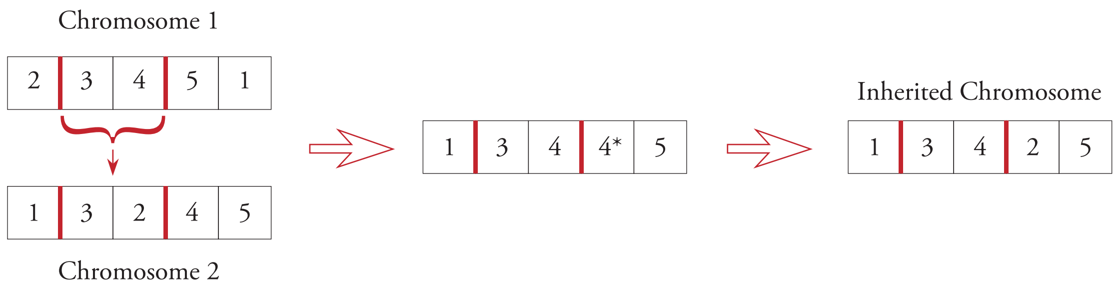



Next, we carry out selection, where the individuals that will be taken to reproduction, in accordance with the results yielded by the fitness function, are defined. After several tests, the SUS-stochastic universal sampling operator was used for the selection process. In the SUS crossover operator a random number is required, and with such number all the individuals that will make part of the reproduction process are obtained.

Once the fittest have been selected, a genetic code combination is performed and as a result, new chromosomes called offspring are produced through the partially matched crossover (PMX) operator. During crossover, a segment of the chromosome chains of one of the parents is copied and inserted in the offspring chromosome; consequently, the blank spaces are filled with information from the other parent, so the genes will not be repeated along the genetic code. Fig. 3 shows an example.

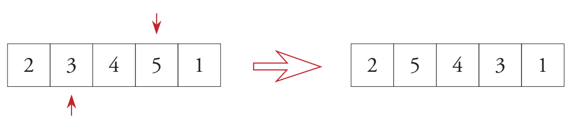
After crossover, mutation comes to have a broader search area space. Mutation consists of modifying certain genes at random. For the case of the object or piece-based representation, the proposed (2-

Fig. 3. PMX operator for GA crossover.




opt) operator was used. This operator consists of selecting two random objects and then swapping positions between them provided both objects do not have the same random number. Fig. 4 shows an example.

Fig. 4. Mutation with a 2-opt operator.




The replacement operator consists of substituting some members of the population with newly generated individuals. The most renowned replacement operator is elitism, which is based on the adaptation function. It prioritizes the individuals with the highest adaptation function to remain in future generations, thus and just as in the natural evolution process, the least feasible solutions are replaced by the best ones.

## Genetic algorithm parameters

In order to select the genetic algorithm parameters, an experiment in which its values varied was carried out; for the case of the number of generations, values of 100, 150, 200 were selected; in mutation, 1%, 5% and 10% values were used; and for the population size values ranging from 10 to 50 were chosen. The response variable is the average waste percentage after five replications of the experiment. Table 1 shows the results of the experiment carried out for parameter selection.

For each parameter combination the genetic algorithm was performed five times, using the case study; then, the parameter combination was determined which presented the best results; in this regard, the best performance was achieved with a number of generations with 200 individuals, a 50 individual population size and a 5% mutation percentage.

Table 1. Experiment for parameter selection.

| **Mutation Rate** | **Number of Generations** | **Population Size** | | | |
|---|---|---|---|---|---|
| | | 20 | 30 | 40 | 50 |
| 1% | 100 | 0,2477 | 0,1963 | 0,2192 | 0,2201 |
| | 150 | 0,2955 | 0,2192 | 0,1963 | 0,1944 |
| | 200 | 0,2533 | 0,2432 | 0,2192 | 0,1963 |
| 5% | 100 | 0,2432 | 0,2399 | 0,2210 | 0,2210 |
| | 150 | 0,2730 | 0,2201 | 0,2210 | 0,2210 |
| | 200 | 0,1988 | 0,2210 | 0,2210 | 0,1899 |
| 10% | 100 | 0,2418 | 0,2477 | 0,2174 | 0,1944 |
| | 150 | 0,2174 | 0,2477 | 0,2192 | 0,2192 |
| | 200 | 0,2174 | 0,2152 | 0,2150 | 0,2150 |

## Application of the genetic algorithm in a case study of cutting pieces out of sheets

I order to test the benefits of the genetic algorithm, a specific case related to the distribution of pieces of a product in a predefined format was set for solving. Some of these pieces are shown in Fig. 5. The sheets used in the manufacturing process are 2.4 meters wide, 1.2 meters high, and 12 mm thick; the total product consists of 20 different components. Since some pieces are repeated several times, there is a problem consisting of cutting a total of 55 pieces.

Even though most of these pieces are rectangles of several dimensions, there are also pieces known as “right angle polygons” (having more than four sides), such as the one shown in Fig. 6a.

Fig. 5. Types of pieces to be cut out of the sheet.

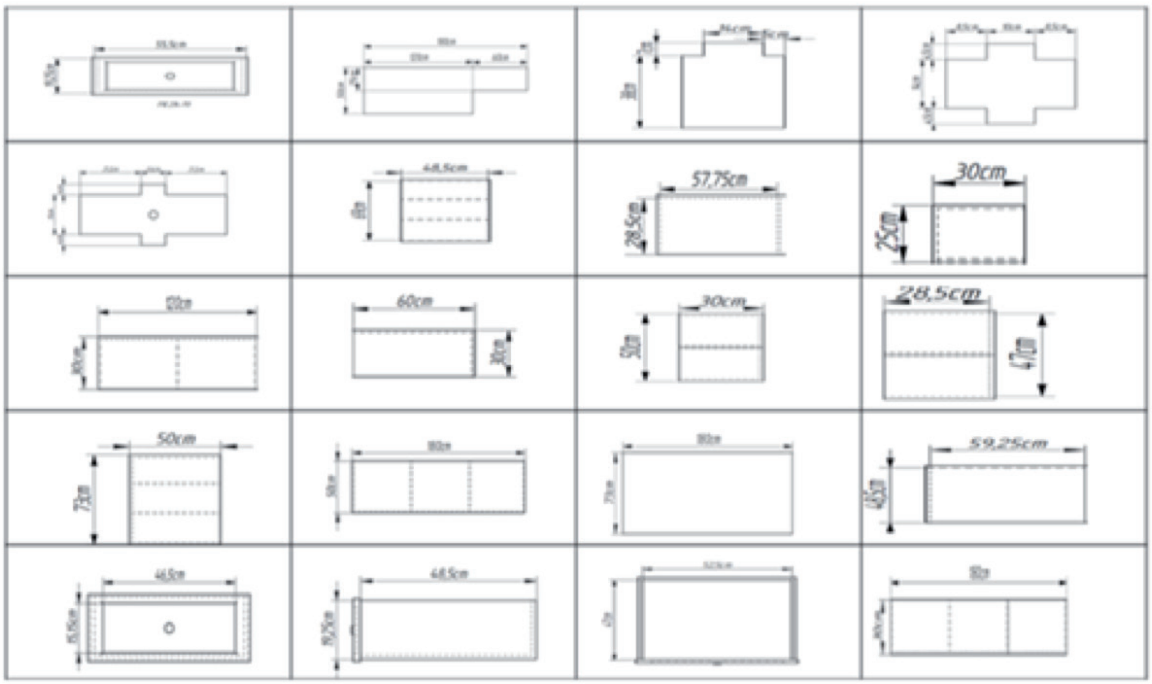
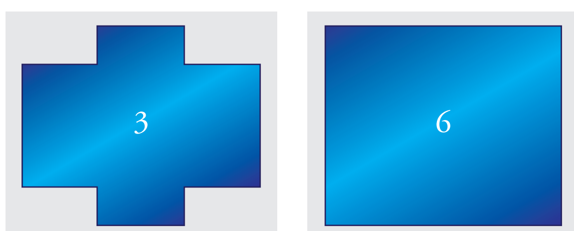



Fig. 6. Piece shapes.




a) b)

This right angle polygon name is due to the fact that the angle formed by every two adjacent sides is a 90 degree angle. In case of the rectangle (Fig. 6b), the same principle applies, considering that not all right angle polygons are rectangles, which affects the heuristics construction that allows placing the pieces in the sheets.

Before solving the case study using the GA, an evaluation of the process of distributing the pieces on the sheets was carried out, as done in the company (manually); for such purpose, the average waste generated in manufacturing 10 products was carried out, with the aid of Equation (15).

$$I_d = \frac{A_{sheet} - A_{AP.sheet}}{A_{sheet}} \times 100\% \qquad (15)$$

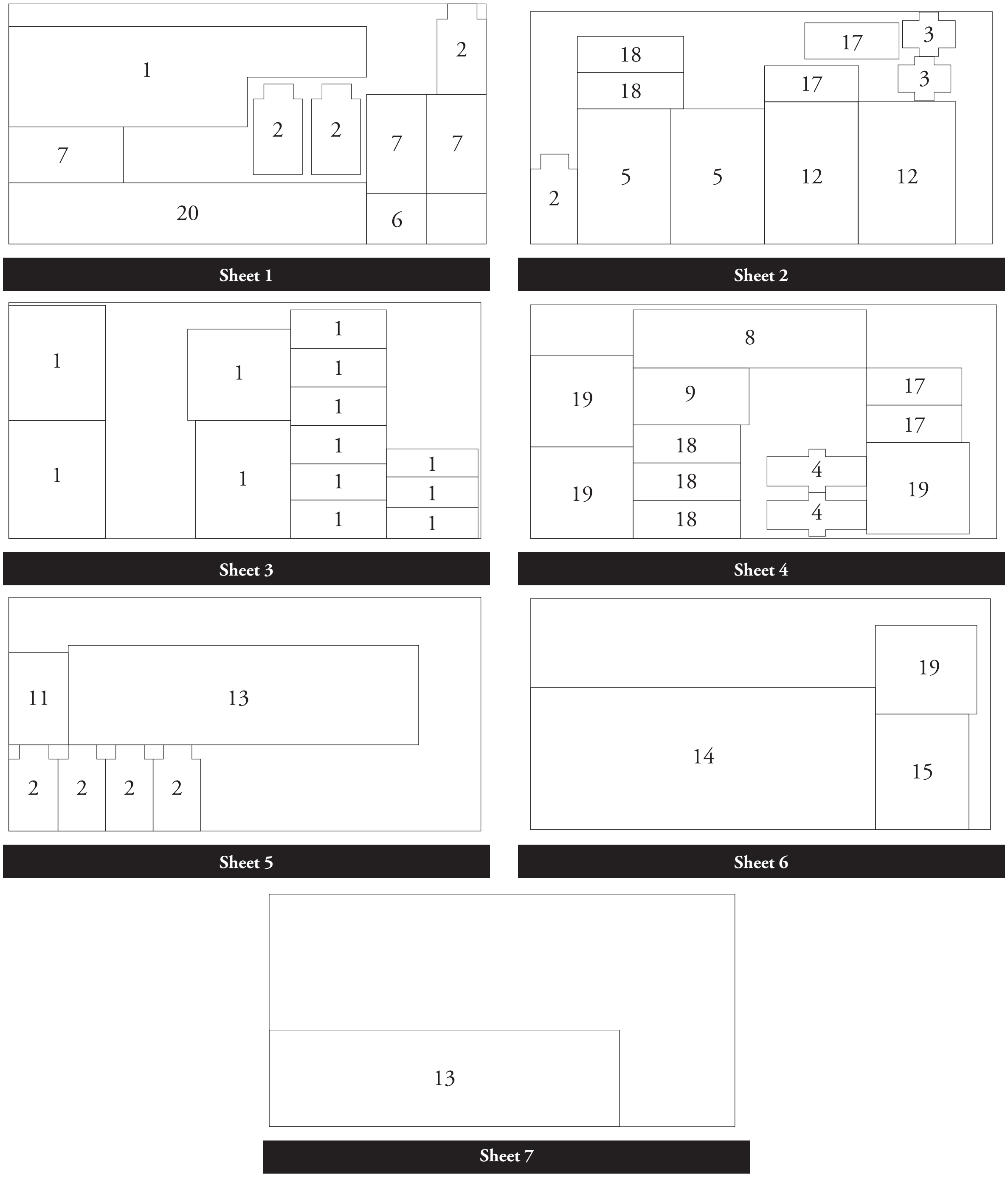
Where $I_d$ represents the waste indicator for a product distribution, $A_{sheet}$ is the total area of the sheets used in distributing a product, considering that the area of the last packed sheet is calculated with the maximum, and $A_{AP.sheet}$ is the total area of the pieces used in distributing a product, or the sum of the areas of all the pieces.

When performing the manual piece distribution based on experience, seven sheets are required, resulting in a total of 18.42 $m^2$ and 31.84% of waste, which is equivalent to 5.88 $m^2$ of the total sheets. Fig. 7 shows the distribution of the pieces over the total sheets for cutting, performed manually and based on experience. The average time associated to distributing the pieces on the formats was 32,5 min.

## Results and Discussion

The Genetic Algorithm was implemented in JAVA and ran on a PC with WIN 7, AMD Turion

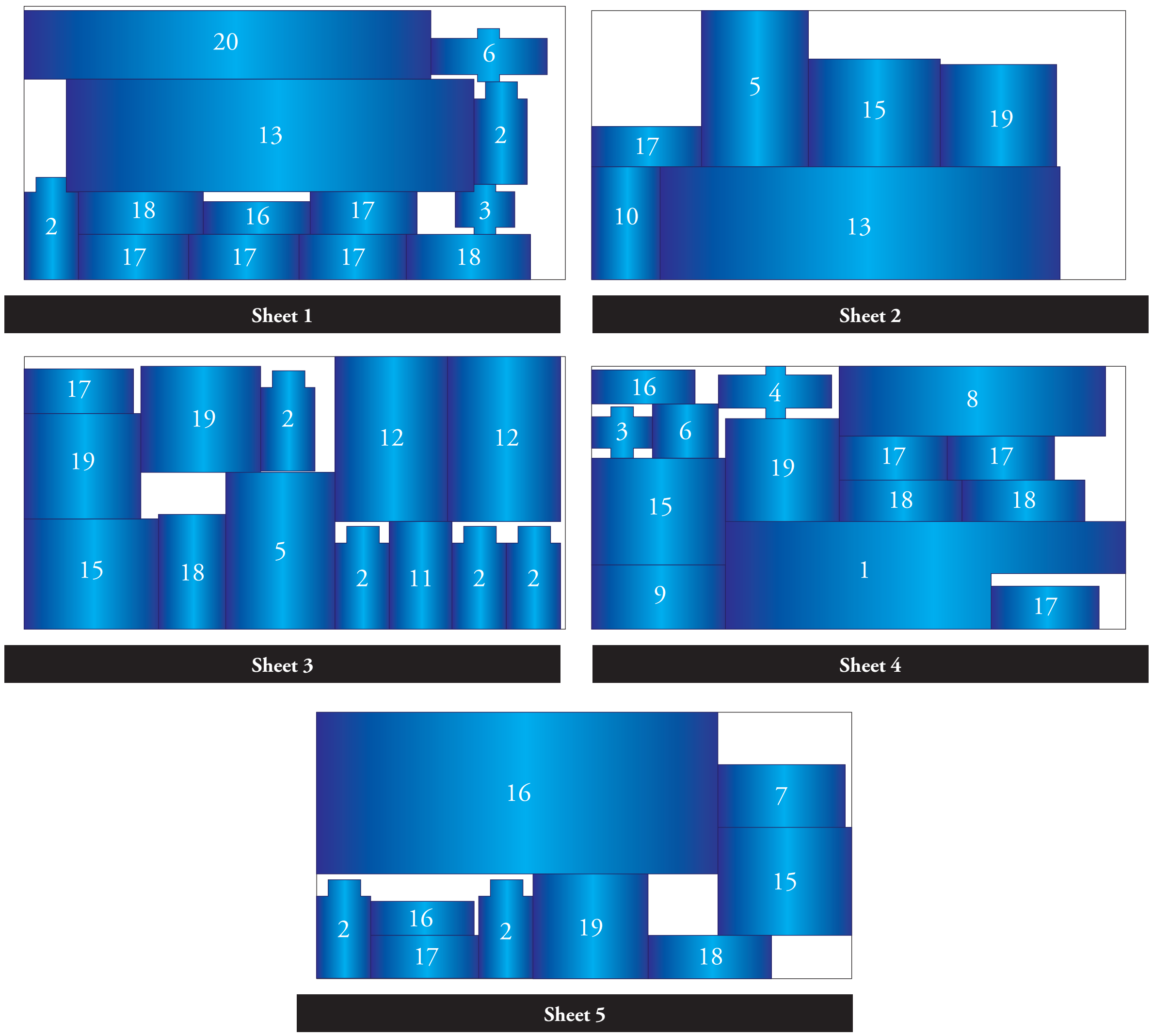
Fig. 7. Distribution of the pieces on the sheets using an experience-based design.




2.00GHz processor, 3 GB RAM and 500 GB HD. The distribution of the cuts generated by the genetic algorithm is shown in Fig. 8. This solution used only five sheets for a total of 15.42 $m^2$ and 21.25% of waste, which is equivalent to a 3.28 $m^2$ area. The average execution time was 8.8 minutes. When this numbers are compared with the average result of the manual distributions, a considerable reduction of 23.67 minutes on average can bee identified.

Considering the diagnosis results and the ones yielded by the computerized tool, Table 2 shows a comparison of the results obtained by the genetic

Fig. 8. Distribution for cutting pieces on sheets using the Genetic Algorithm.




algorithm vs the results of the experience-based manual distribution.

Table 2. Comparative results chart.

| Description | Wasted per product | | |
|---|---|---|---|
| | % | Área (m²) | Cost |
| **Genetic Algorithm** | 21.29% | 3.286 | $75,314.84 |
| **Manual Distribution** | 31.84% | 5.88 | $134,842.40 |
| **SAVINGS** | 10.55% | 2.594 | $59,527.56 |

The implementation of genetic algorithms yields savings of 10.55 percentile points of the total waste area, which is equivalent to 2.594 $m^2$, adding up to $59,527.56 Colombian Pesos saved.

## Conclusions

The issue of distributing pieces on sheets considering right-angled pieces, known in literature as the 2D-BPP problem was solved by implementing a genetic algorithm. Two benefits were accomplished through this work: first, regarding waste percentage, by reducing 1.55 percentage points, which leads to cost reduction.

Also, a reduction in the administrative workload used to generate the distributions of the cuts on the sheets, which translates into an increase in productivity was observed.

For future works, including 90° rotations will be considered, in order to seek higher waste reduction indexes in sheet cuts. Also, the possibility of allowing the algorithm to cut curved pieces is suggested.

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## Annex 1. Model parameters and variables

***Parameters***

- *N*: Number of rectangles available to place on the sheet of material.
- *L*: Sheet length.
- *W*: Sheet width
- $p_i$: Length of rectangle *i*.
- $q_i$: Width of rectangle *i*.

***Variables***

- ($x_i$ , $y_i$): Variable indicating the position of rectangle *i*, with the bottom left corner of the sheet as reference.
- $s_i$: Binary variable that indicates if rectangle *i* was located on the sheet.
- ($l_{xi}$ , $l_{yi}$) : Binary variable that indicates the axis of the sheet of material. The $p_i$ side of rectangle *i* is parallel to it.
- ($w_{xi}$ , $w_{yi}$): Binary variable that indicates the axis of the sheet of material. The $q_i$ side of rectangle *i* is parallel to it.
- $a_{ik}$: If its value is 1, indicates that the rectangle is on the left side of rectangle *k*.
- $b_{ik}$: If its value is 1, indicates that the rectangle is on the right side of rectangle *k*.
- $c_{ik}$: If its value is 1, indicates that the rectangle i is behind rectangle *k*.
- $d_{ik}$: If its value is 1, indicates that the rectangle i is in front of rectangle *k*.
- *M*: A very large integer.

# Increasing the Reliability of a Naval Tactical Data Link through the Design and Implementation of Automatic Mechanisms for Failure Recovery

Incremento en la fiabilidad de un enlace táctico naval mediante el diseño y la implementación de mecanismos de recuperación automática ante fallas

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## Abstract

This document describes the design and implementation process of an automatic failure recovery system on a tactical data link, with the purpose of increasing its reliability during the execution of command and control naval operations. This effort is part of a project that seeks to create a Command and Control System at an operational level. The design of the recovery mechanism begins with the state analysis of the data link system under study, it then, continues with the identification of possible "dead states" and finally, turns to the development of software solutions for each identified failure. This solution considers the communication infrastructure capabilities currently available in the Navy units, so its implementation costs are reduced. This paper also presents the results obtained from the tests carried out in the system, which show that the average failure recovery time was reduced by 50%, increasing the reliability of the analyzed data link.

**Key words:** Tactical Data Link, Automatic Failure Recovery, Command and Control, Communications network.

## Resumen

Este documento describe el proceso de diseño e implementación de un mecanismo de recuperación automático ante fallas, en un enlace de datos tácticos, con el fin de incrementar su fiabilidad durante la ejecución de actividades de mando y control de operaciones navales. Este trabajo es parte de un proyecto que pretende crear un sistema de comando y control a nivel operacional. El diseño de los mecanismos de recuperación inicia a partir del análisis de los estados del sistema data link bajo estudio, continúa con la identificación de posibles estados muertos y finalmente, se presenta el desarrollo de las alternativas de solución por software para cada falla detectada. Esta solución contempla las capacidades de infraestructura de comunicaciones disponibles actualmente en las unidades de la Armada, por lo que sus costos de implementación son reducidos. Este documento también presenta los resultados obtenidos a partir de las pruebas efectuadas al sistema, con las cuales se evidencia que el tiempo promedio de recuperación ante una falla se redujo en un 50%, lo que incrementa la fiabilidad del data link analizado.

**Palabras claves:** Enlace de datos tácticos, recuperación automática de fallas, comando y control y red de comunicaciones

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## Introduction

Currently, when the units of some military components operate in groups/task forces, tactical information transfer among them is crucial, in order to provide a common tactical view that enables real time coordination of operations.

This information exchange must be executed through a system that ensures privacy, that is reliable, user friendly and that, because of bandwidth constraints in the available means of communication (HF - V/UHF), does not overly increase message size.

However, failures that reduce system reliability may occur during the operation. These failures may be attributed to system design issues (dead states), physical network problems (equipment failure, unit disconnection), or electronic warfare technologies used to interfere and override these types of systems.

In order to ensure the reliability of this type of system, we must thoroughly study the media access control mechanism of the tool and the system states, and identify possible failure conditions. The above, in order to be able to design automatic recovery mechanisms suitable for the analyzed system, with minimum investment in specialized hardware and applying solutions from the software component, using system synchronization as a starting point.

This work describes the methodology used to design and implement an automatic recovery system for failures detected in a tactical data link system and how this will increase the system's reliability by reducing average recovery times.

## Characteristics of the system under study

The system under study is the prototype version of a Tactical Data Link developed by COTECTMAR for the Colombian Navy.

A Tactical Data Link is a tactical communication system based on radio communications that enables running the tactical information of a force or task force and improve decision making and command and control functions through information exploitation tools *(COTECMAR, 2011)*.

Tactical Data Links (TDL) enable radio data exchange between platforms, in order to minimize voice communications that may be critical in action or combat environments *(CPT/CIA, 2008)*. Its basic operating principle is to provide a real time link between subordinate units and their corresponding operational command. Currently, a large portion of military communications (voice and non-voice) are transmitted as data, making it easier for the military forces to coordinate their land, sea, and air-based operations *(Asenstorfer, Cox, & Wilksch, 2004)*.

Technically, TDLs define a family of protocols known as Links, that have broadened military communication coverage through wireless networks that connect vessels, submarines, tanks, land bases, etc. These protocols lie within the physical and link layers (one and two, respectively) of the OSI reference model, defining aspects regarding Media Access Control (MAC) and information transmission on the radio links *(Benavides & Montañez, 2008)*.

Technical characteristics of the system under study:

- Includes a cartographic system in S-57 and Shape format.
- Operates on HF/VHF/UHF frequency bands.
- It has AES private key cryptography.
- Three operating modes: Test, Silence, and Normal (operating).
- FSK modulation
- On-demand (polling) MAC. This implies that there must be a network controlling station.

Functional characteristics of the system under study:

- Operation management (unit configuration, charts and groups)
- Network management (codes, network modes, radio communication options)
- Weapon management

- Tactical information exchange (position reports, contacts, changes in configuration, unofficial messaging, alerts, correlation/decorrelation, among others).
- Information exploitation and decision making support (RAM traces, points of reference, radar prediction, interception, PMA, position simulation).

Hardware components of the system under study:

The described system is accompanied and complemented by a hardware component that ensures integration of all the system functionalities with the radio communication equipment required to carry out the information exchange in the network.

System hardware consists of a communications integrated box, which incorporates COTS[1] components, such as: a multi-modem card to modulate and demodulate FSK data in the communication channels, a switch card with 8 ports to connect the on-board devices, an internal 12V and 5V DC source to power the cards and adaptors for all internal connections.

The box has an external 115VAC and 12VDC supply. It has a universal USB port for PC connection and serial ports to connect radio equipment.

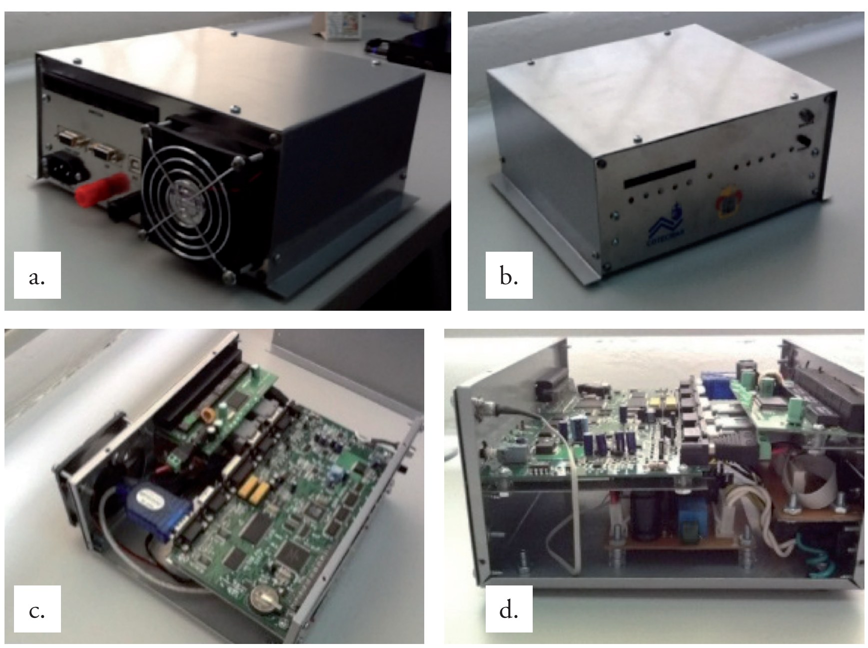
Fig. 1 shows images of the communications integrated box.

Fig. 2 shows the process followed in managing the system network. Basically, the Data Link is seen as a tactical data link between the participating units in a specific operation.

During the process of exchanging tactical information to support decision making while performing the operation, the following resources are involved:

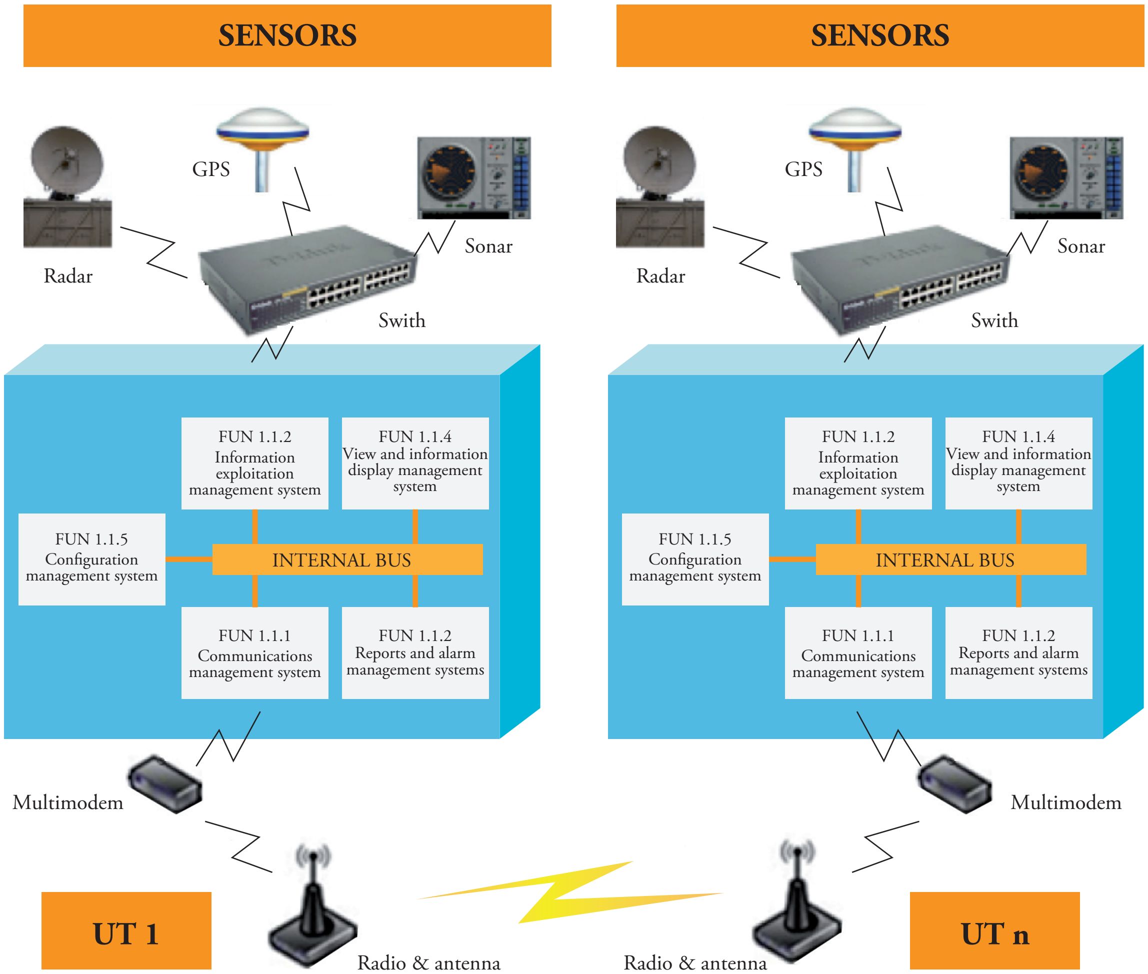
- The sensors in each unit, which become combat intelligence information sources which is shared with all units.
- The analysis tools that support decision making.
- The external communications system of the units.

Fig. 1. Communications integrated box. (a) rear view, (b) front view, (c) top view, (d) side view.




[1] Commercial Off-The-Shelf. Non-developing element (NDI) for supply, which is also commerciall.

Fig. 2. Expanded view of the system under study.




- The data modulating and demodulating devices, to be adapted for radio communications.
- Means to deploy information.
- Database managing systems that store information during the operations.

## Failure identification and design of recovery mechanisms

Fig. 3 shows the flowchart for the system under study for the "Normal" operation mode.

During system operations, failures may occur in some participating unit due to internal or external factors, which would cause such unit to involuntary lose connection or a significant disturbance in communications.

Below are these type of situations, for which the recovery processes of the system have been taken into consideration.

- Disturbed media (ECCM).
- Fall of the Network Controller Station (NCS) or Control Unit (CU).
- Fall of the unit with the token.
- Fall of a participating unit.

Visualization of these failures in a more detailed system scheme is shown in Figs. 4 and 5, for the CU and PU roles, respectively. Failure situations are shown in red in the schemes.

Fig. 4 shows two possible failures, seen from the CU:

Fig. 3. General system flowchart.

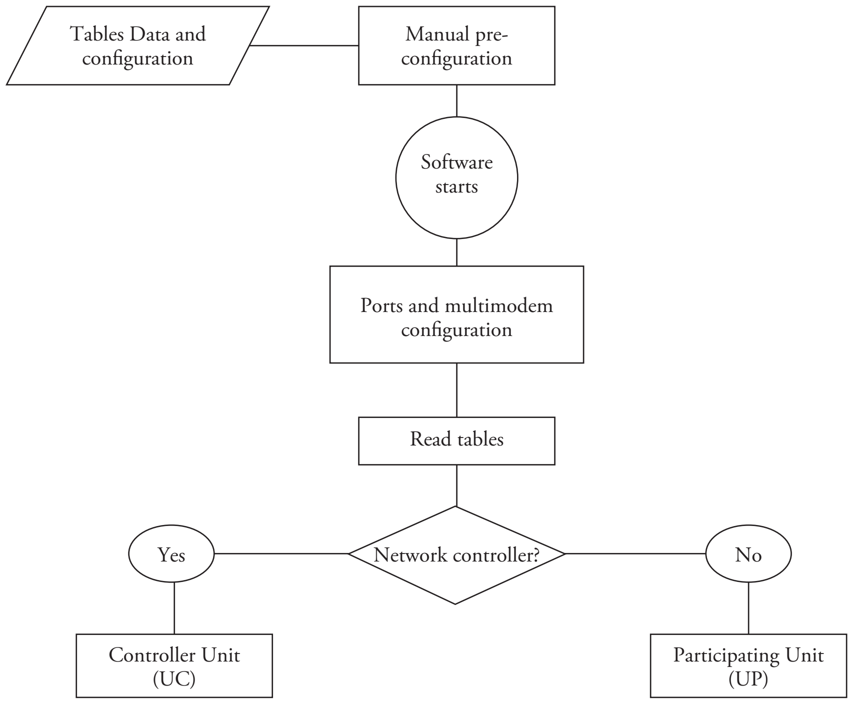


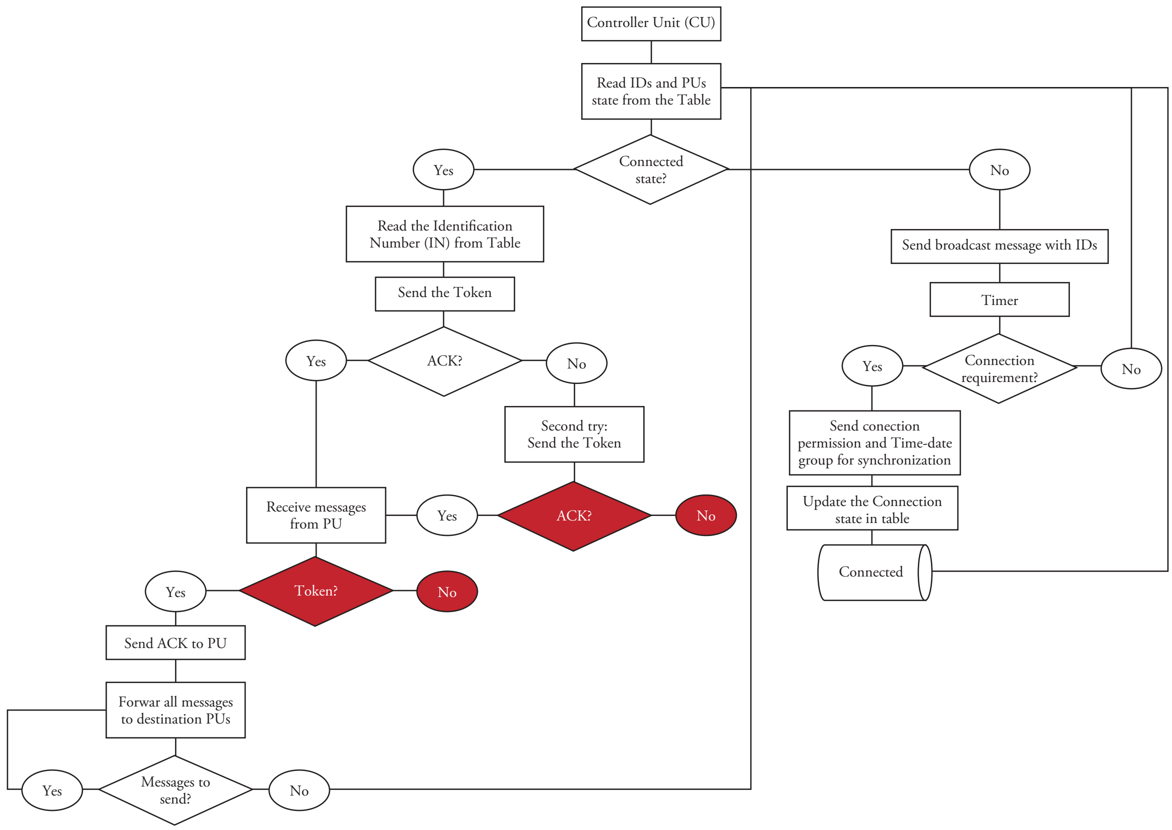

Table 1. System failure identification.

| Mutation Rate | Number of Generations | ORIGIN | AFFECTS |
|---|---|---|---|
| Disturbed media | The transmission channel is blocked by a higher power signal and therefore information cannot be received/transmitted. | External | NCS - PUs |
| Fall of the NCS | The network control station becomes disconnected and therefore the network coordination actions and information relay cannot be performed. | Internal – NCS | PUs |
| Fall of the PU with Token | The participating unit that receives the token disconnects and does not return the Token to the NCS, and therefore communications in the network are affected. | Internal – PU | NCS – PUs |
| Fall of the PU | A participating unit disconnects when it does not have the token; as a consequence, it cannot receive/transmit information. | Internal – PU | PU |

The first one (from top to bottom) is the dropout of a PU. The controlling unit sends the token to the PU and since no ACK is received, it repeats the attempt; however, the design of the system considered only the possibility of the PU reconnecting during that second opportunity, ruling out the option of voluntary or accidental disconnection of the PU; therefore, upon reaching this point, the system fails and it cannot find a state in which to operate, thus completely disconfiguring the network.

The second failure is the dropout of a PU with token. In this case, the participating unit receives the token sent by the PU, replies the ACK, and therefore the CU sent all the information available to the PU and also receives all the information coming from it, but in the end it does not receive the token. This option was not considered during the design of the system, and therefore upon reaching this point, it fails and cannot find a state in which to operate, thus completely disconfiguring the network.

Fig. 4. Detailed flowchart of the Network Controlling Unit.




Below, Fig. 12 shows the moment (seen from the PU) that generates two of the most complex failure situations:

In the current system design, it is assumed that once connected to the network, the PU will always receive the token from the CU; however, whenever the controlling unit voluntarily or involuntarily disconnects, there is no way to generate a token in the network or to manage the information exchange between the units, and therefore the system will enter into an infinite silence or the network will disconfigure since the ID of the controller unit authorizing connections will not be detected.

Now, given the naval environment in which this type of systems are used, it is possible that both the PU and the CU are connected but fail to communicate because the communication channel is blocked or disturbed (electronic warfare techniques); in this case, the PU will also assume that the CU is not connected, and therefore the point of origin of the failure is assumed to be the same one.

## General design – failure recovery

The sequence diagrams (Figs. 6-8), show an overview of the recovery mechanism to be implemented in each case.

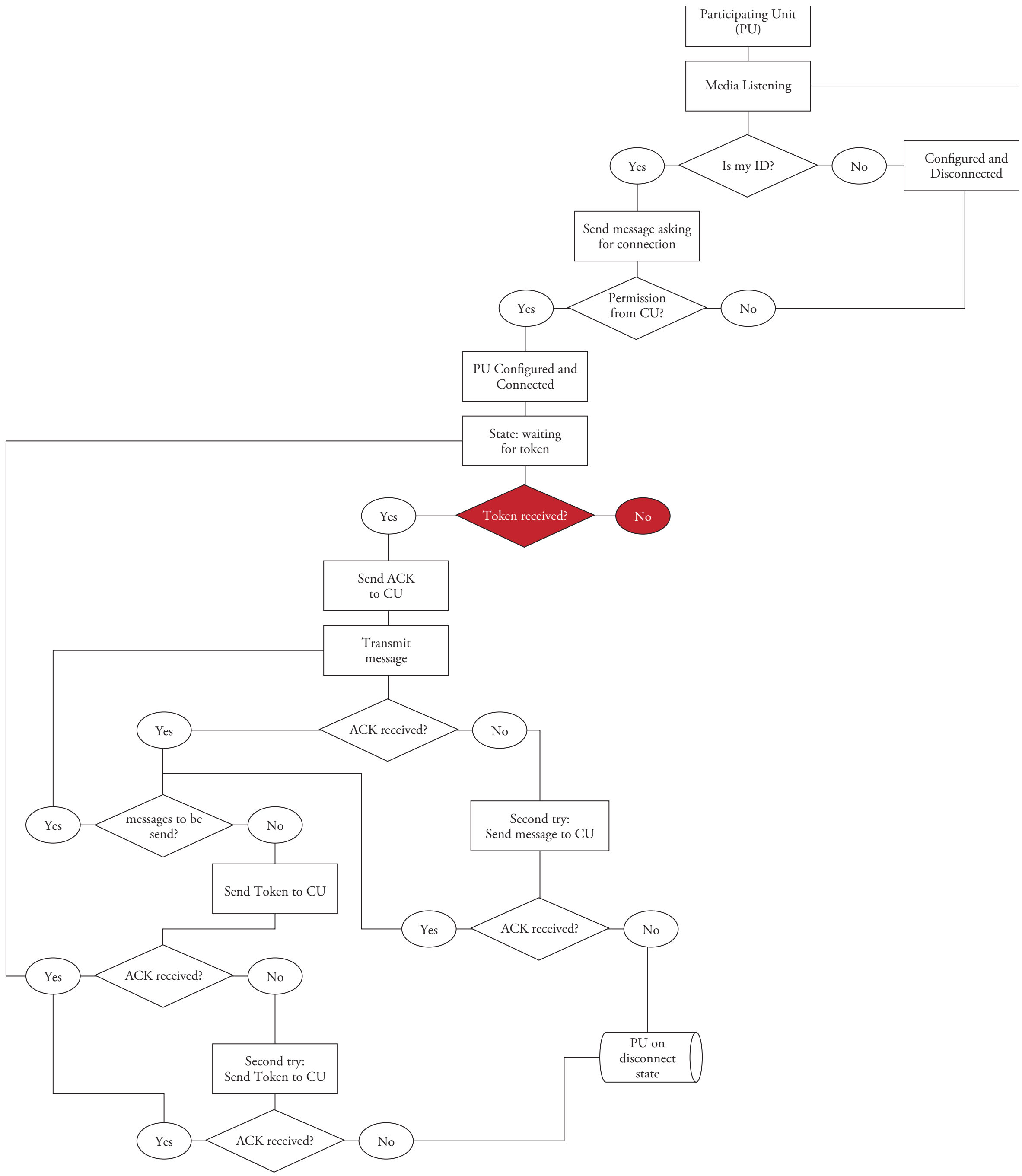
## Detailed Design – Failure Recovery

Considering the media access control of the system, and knowing that the main issue is to reduce recovery times, timers are implemented in the system as mechanisms to activate identification and fail recovery routes.

These timers will be based on the times designed for system synchronization; such times are listed and described below:

- *To*: Network performance optimized time.

Fig. 5. Detailed flowchart of the Participating Unit.




- *Te*: Lead time. It starts with a reception silence after a unit already has received the token. It is equivalent to 2*To*. This metric resets every time the NCS receives a message.
- *Tdisturbance*: Waiting time to receive connections. It allows to determine if the disturbed media (ECM) situation is present. It is equivalent to *NTo*, where *N* is the number of units in the table.
- *Tic*: Waiting time for units to switch to the new frequency (ECCM) and to synchronize the reconnection process.
- *Treconnection*: Time period that begins at the end of *Tic*, until the connection time is

finished (it is also equivalent to *NTo*).

- *Tet*: Time between tokens. It is the time of a token cycle. It is comprised by a time slot for each unit and multiplied the number of units in the table.
- *Tcr*: Network cycle time. It is the time it takes to ensure that all units are aware of the NCS dropout.
- *Tcm*: Multi-modem configuration time. It is the time taken for the multi-modem to configure as an NCS.

It is noteworthy that during the token cycle, whenever a unit is disconnected, the NCS must

Fig. 6. General design for a UP with Token dropout recovery.

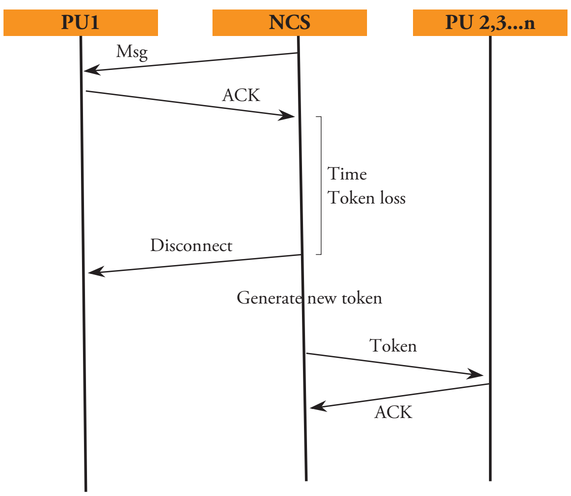



Fig. 7. General design for a UP dropout recovery.

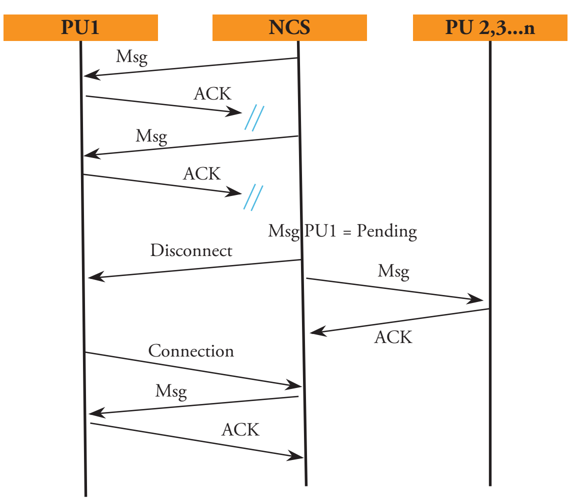
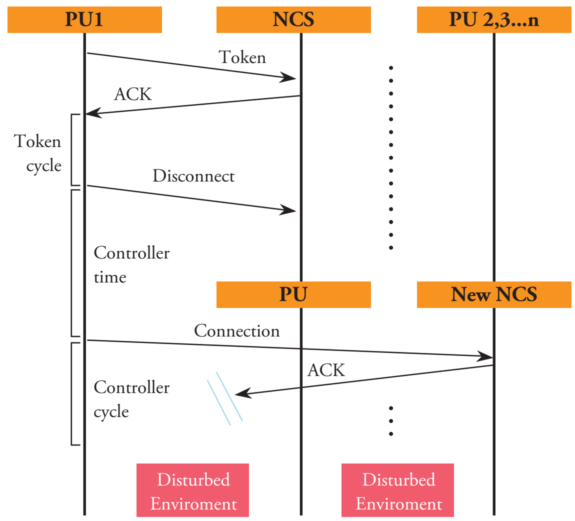



Fig. 8. General design for an ECR dropout and Disturbed Media recovery.




wait for a *Tc* time so that such unit may have a time frame to connect to the network. TC is equivalent to 2*To*.

The "Disturbed media", "fall of the PU with Token", and "Fall of a PU" failure situations described in Table 1, will have a network recovery procedure seen from the CU or NCS as shown in Fig. 9.

The "fall of the NCS" failure situation shown in Table 1, shall have a network recovery period seen from the PUs, as shown in Fig. 10.

Generally, the recovery mechanisms are explained as follows: in CU a timer (te) is triggered as soon as the unit receives the token ACK message, *i.e.* as soon as token delivery to a PU has been confirmed.

In the case of fall of the PU failure, this timer is not triggered, since the PU does not receive the token message. The proposed solution in this situation is disconnecting the unit after the second attempt to deliver the token, and to continue monitoring the connected PUs sequence to send the token. Thus, the affected PU may detect its inactivity and request a new connection in a subsequent token cycle. With this solution, the network will not lose its configuration and only the unit with problems will be affected.

Fig. 9. Sequence of actions for the automatic system recovery (associated to UP dropout).

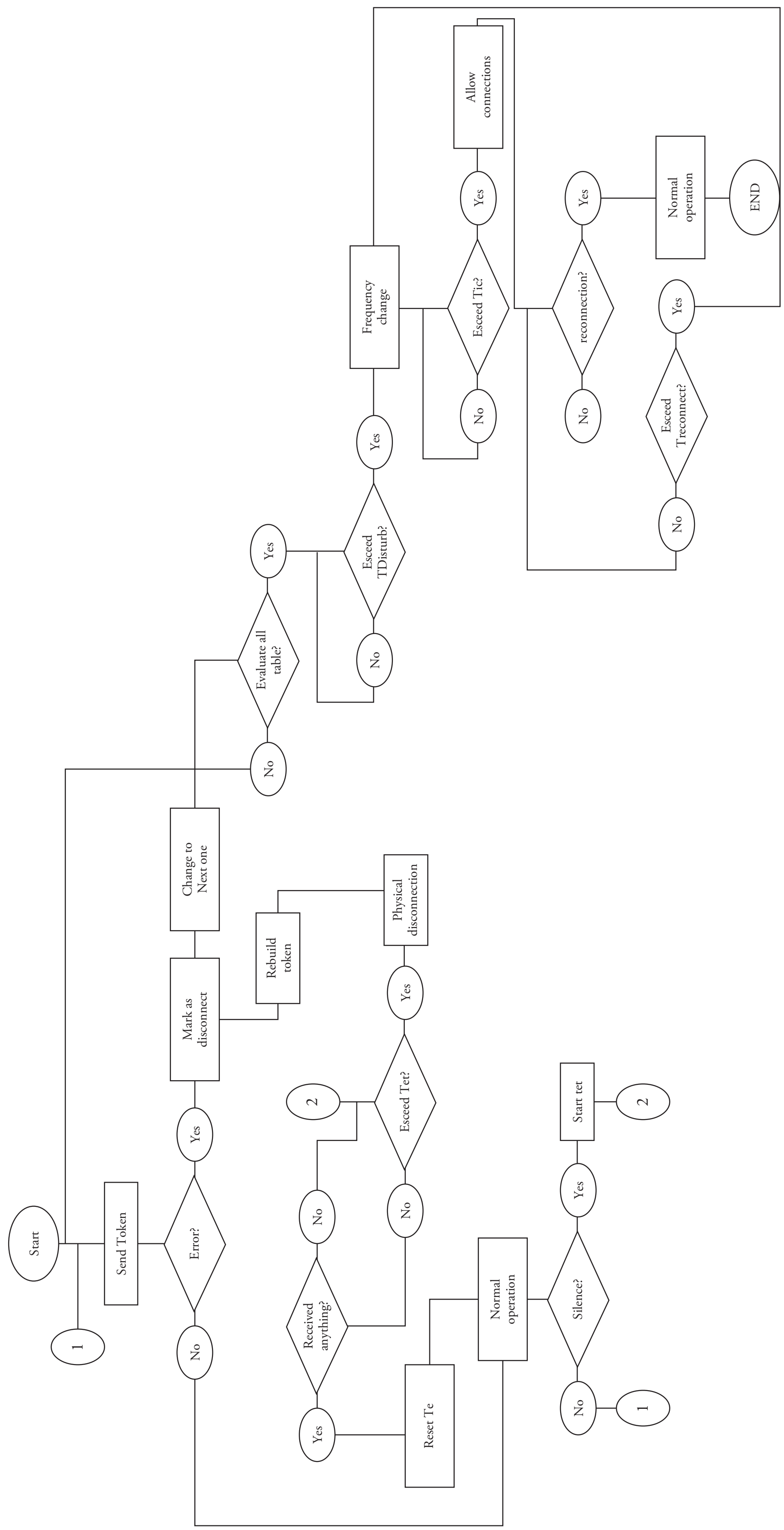
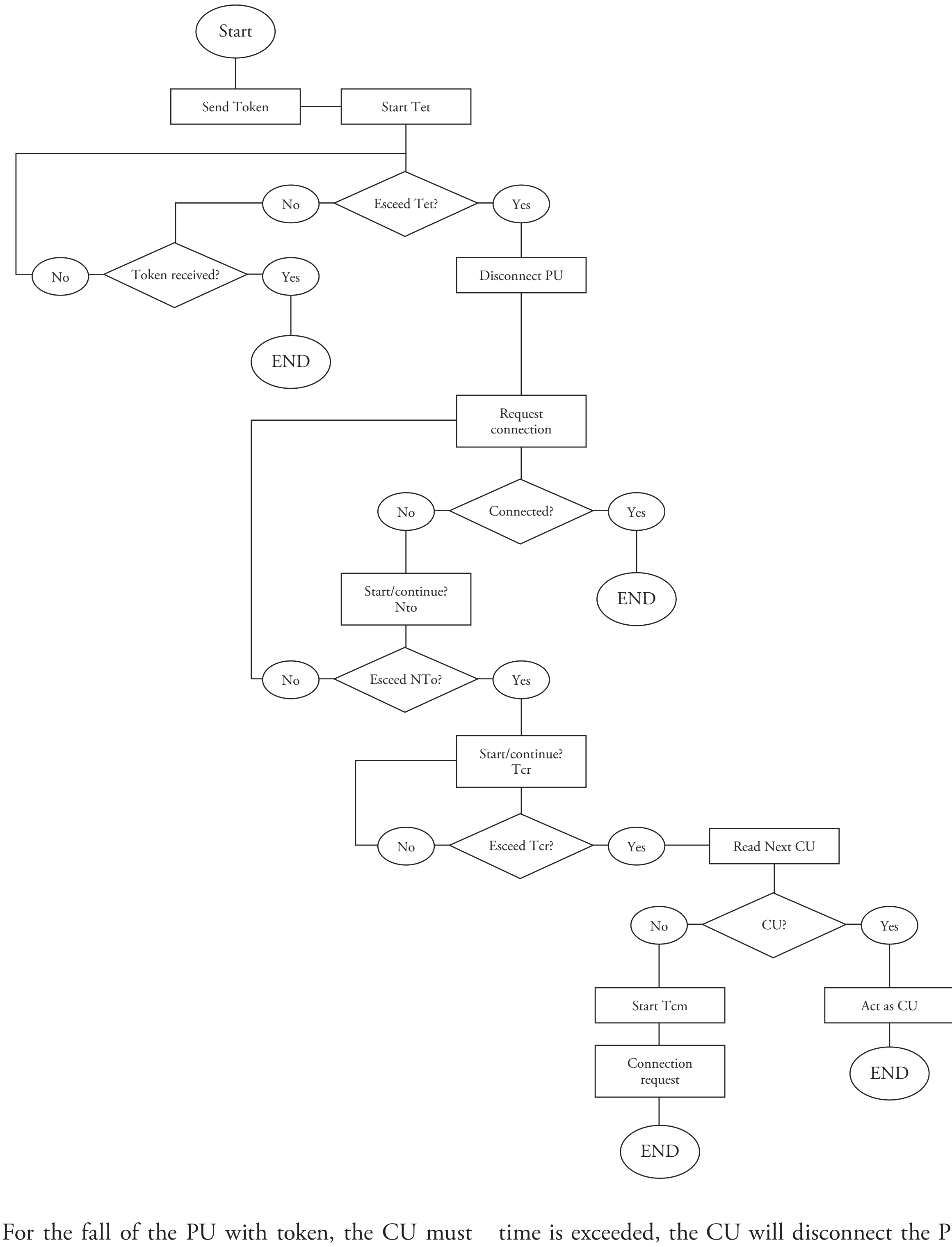


Fig. 10. Sequence of actions for the automatic system recovery (associated to an ECR dropout).




For the fall of the PU with token, the CU must verify the "expiration" of the timer time (*te*). The purpose of this is to provide a reasonable time frame for the PU that has the token to transmit information or to reclaim the token. Once this time is exceeded, the CU will disconnect the PU and invalidate the previous token, generate a new one, and continue with the token sequence. Thus, there will be no two tokens in the network and only the failed PU is affected.

From the PU perspective, the two above mentioned procedures are not detected, unless it is the PU that had to be disconnected from the network, *i.e.* the failed PU. In this case, once each unit is connected and configured in the network, the timer (*tet*) that allows it to remain in a token-standby status is triggered. If such timeframe is exceeded, the PU shall check if it remains in a connection state; if so, it shall automatically disconnect from the network and trigger a second timer (*tcr*). During this time frame, the PU shall remain in a "listening" mode. If it hears its ID (which is sent off by the CU) within this timeframe, it automatically sends its connection request message to the network again.

If, given the final condition set forth in the previous paragraph, the environment is still silent and the (*tcr*) time is exceeded, the PU will automatically recognize that something happened to the CU, and it will therefore proceed to verify if it is its turn to assume CU functions. If so, the unit will auto-reconfigure and assume the CU functions. If not, a third timer (tdisturbance) will trigger. If this timer is exceeded, the PU shall interpret that it is being disturbed and will check the configured frequency table to suggest the operator switching to a secure frequency.

## Failure identification and design of recovery mechanisms

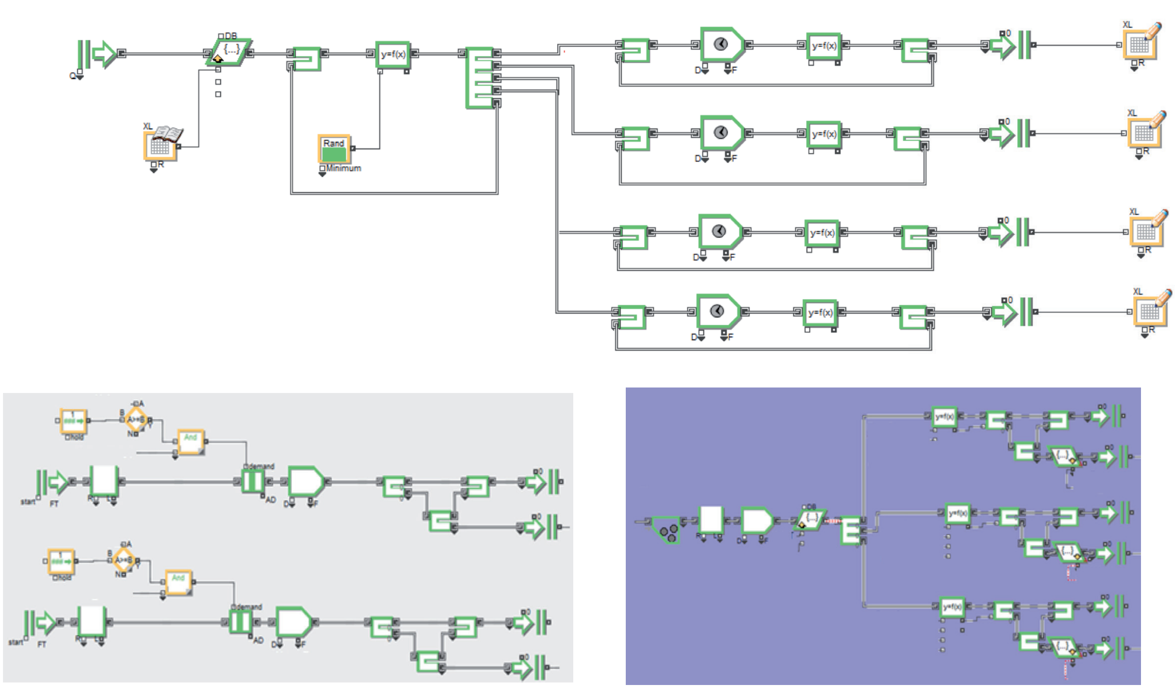
The simulation model made for the system is shown below. The entry variables for the simulation are read from an Excel spreadsheet with the entry values for the simulation. The purpose of this model is to assess how entry variable variation affects output, in order to select the values that yield the best performance, for implementation in the system.

- Entry variables: Amount of Participating Units and Optimized Network Time.
- Output parameters: recovery time.

For the simulation, a failure in the system is assumed, using a random value distribution module of values ranging between 0 and 3. Said values lead the system to a failure (according to the details in Table 1). For each type of failure, a timer is activated and the recovery actions are taken, according to the figures shown in the previous section.

Fig. 11 shows the general layout and some sub-processes of the simulation model made with the ExtendSim 8 computing tool.

Fig. 11. General layout for the simulation model.



In order to simulate the recovery mechanisms, the times that the system takes to perform certain actions during experiments, such as table reading, ID identification, among others, to achieve admissible ranges in the model were taken as model input.

The simulation was ran 1000 times, and the first 100 results of the recovery time for each type of failure were taken as study data.

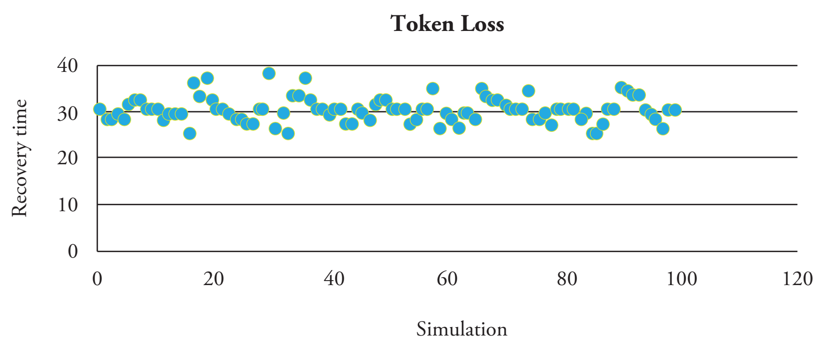
The simulation model was implemented for the following input conditions:

- Amount of units: 4 (Maximum number of units participating in operations)
- Network optimization time: 3.9 seconds (measured value)

## Simulation Results

The results obtained from the simulations are shown below.

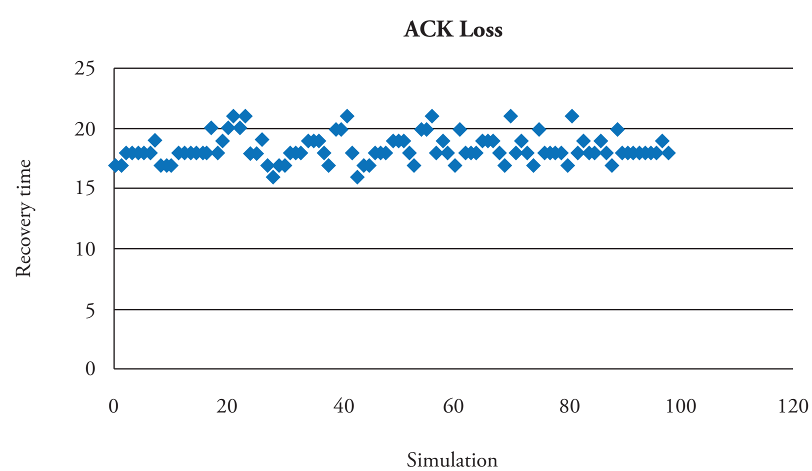
Fig. 12. Achieved results – recovery time for token loss dropout.




The minimum recovery time of the simulation was 25 seconds, while the maximum time was 38 seconds.

- Average recovery time: 29.9 seconds.
- Standard deviation: 2.65

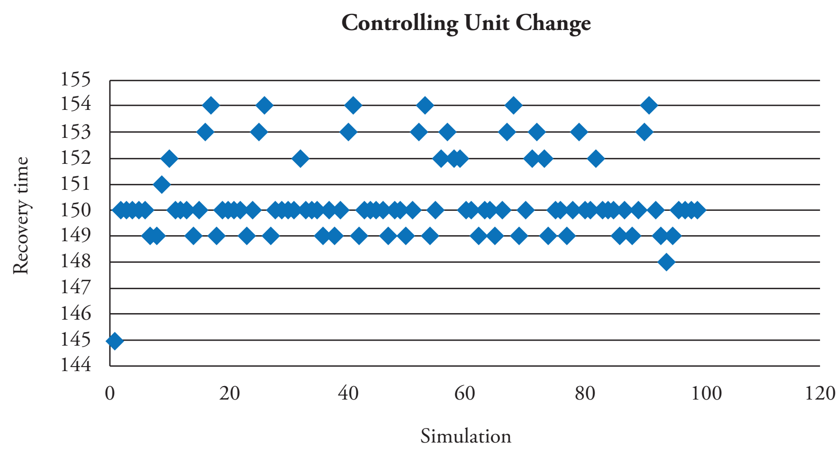
Fig. 13. Achieved results – recovery time for ACK loss dropout




The minimum recovery time in the simulation was 16 seconds, and the maximum time was 21 seconds.

- Average recovery time: 18.35 seconds.
- Standard deviation: 1.12

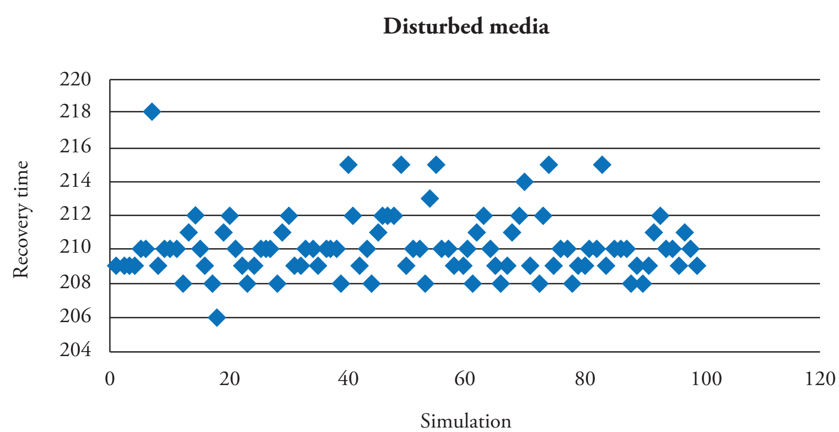
Fig. 14. Achieved results – recovery time for controlling unit change.




The minimum recovery time in the simulation was 145 seconds, while the maximum time was 154 seconds.

- Average recovery time: 150.4 seconds.
- Standard deviation: 1.57

Fig. 15. Achieved results – recovery time for disturbed media.




The minimum recovery time in the simulation was 206 seconds and the maximum time was 218 seconds.

- Average recovery time: 210.13 seconds.
- Standard deviation: 1.91

The table below summarizes the recovery times measured in the system simulation.

As a result of the simulation process, we verified that the recovery times associated to each failure

Table 2. Summary of simulation results.

| Test Name | Number of Repetitions | Standard Deviation | Average Time |
|---|---|---|---|
| System recovery for token loss | 100 | 2.65 | 29.9s eg |
| System recovery for ACK loss – fall of a PU | 100 | 1.13 | 18.35 seg |
| System recovery for change in controlling unit | 100 | 1.57 | 150.4 seg |
| System recovery for a disturbed medium | 100 | 1.91 | 210.13 seg |

dropped in over 50% as compared to the times measured in manual system recovery; therefore, we confirm the feasibility of implementing the proposed mechanisms.

The programming language used to implement these mechanisms is C++, and the work environment was Visual Studio 2010. We used a licensed version of this tool, property of COTECMAR.

The timers implemented in the system as a comprehensive part of the proposed failure recovery model are shown in Fig. 16, which presents, in the Visual Studio 2010 graphic interface, the corresponding icons and names assigned to each one of them in the system.

## Tests and implementation results

In order to verify the lab performance of the automatic fail recovery mechanism implementation, we drew a test plan consisting of four (04) packages (1 for each type of failure). The devices and/or tools considered to run the Test Plan are:

- Four computers in working conditions, with Windows XP or higher, installed and updated (in this specific case we used 04 standard DELL Latitude E6400).
- Radio equipment comprised by:
- Four tactical radios with antenna charger, Motorola Pro 3100 UHF, with power source.
- Four communication integrating boxes.
- Wiring suitable to connect computers, multi modems and radios.

Fig. 17 shows a picture of the laboratory where tests were held. This lab is located in the COTECMAR facilities in Cartagena, and its use was authorized to runt the testing protocol of the system under study, with the implemented automatic failure recovery system.

The summary of the results obtained in the lab tests is shown in Tables 3-4. Table 3 shows the operating results, i.e. if after the failure, the network could be returned to an operating state. On the other hand, Table 4 shows the average recovery times for each one of the 50 tests ran for each type of failure.

Fig. 16. Visual Studio 2010 user interface –implemented timers.

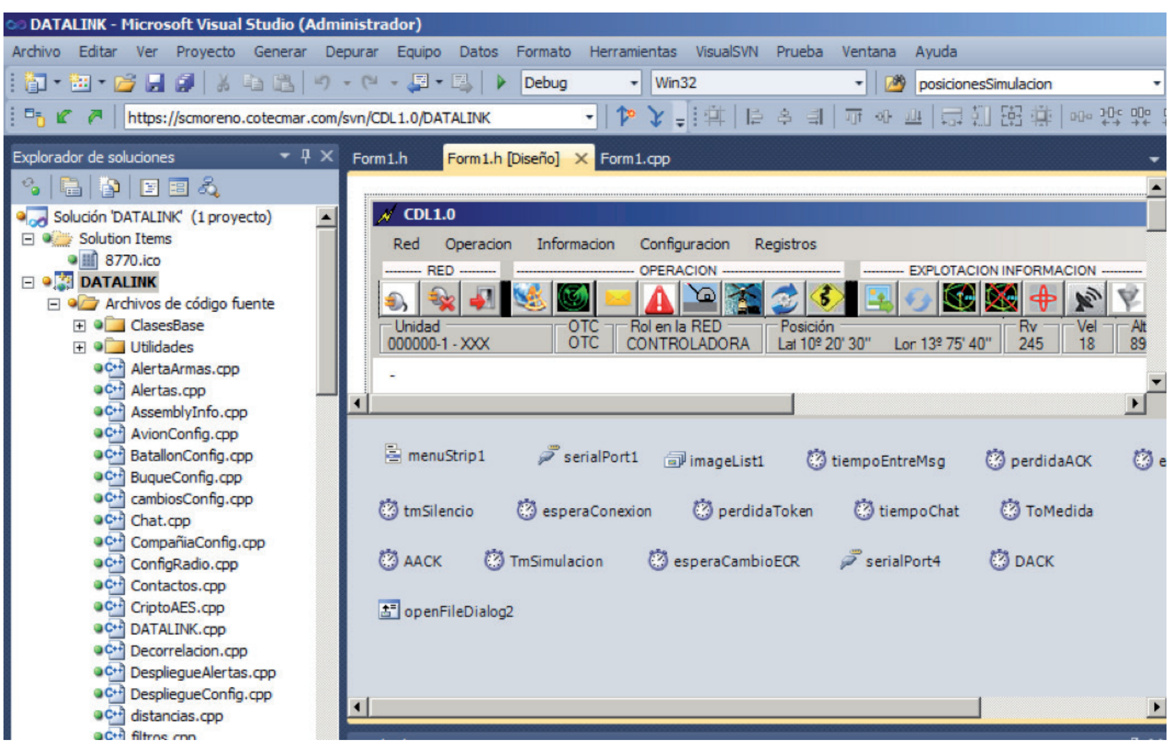
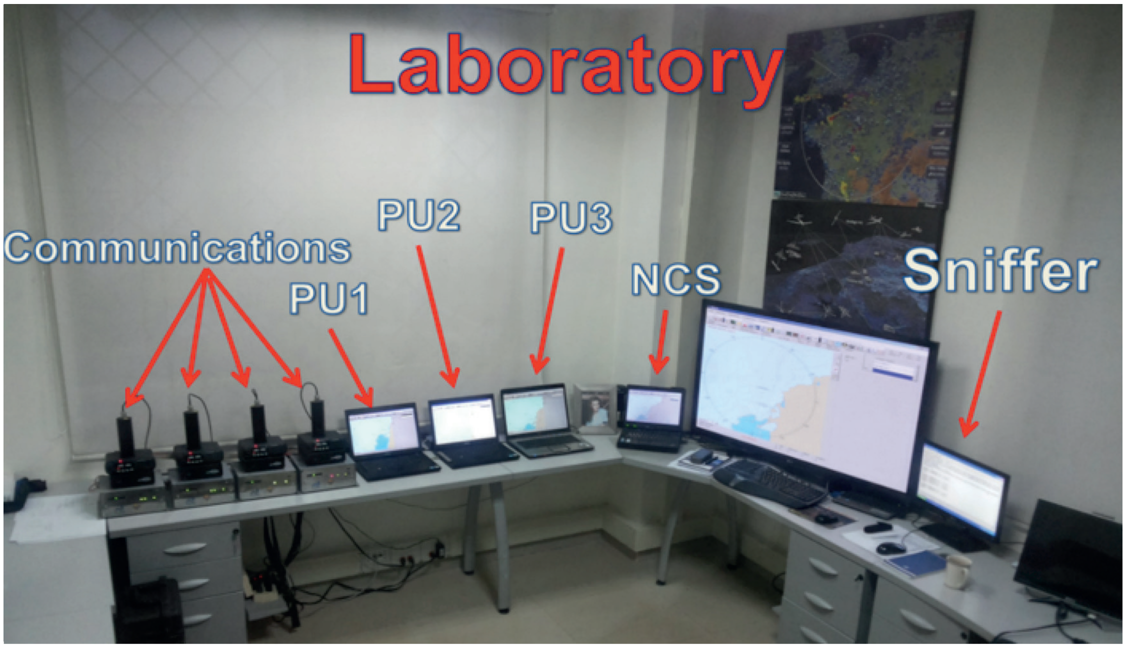


Fig. 17. Lab facilities where the tests were held.




The summary of the results obtained in the lab tests is shown below. Table 3 shows the operating results, *i.e.* if after the failure, the network could be returned to an operating state. On the other hand, Table 4 shows the average recovery times for each one of the 50 tests ran for each type of failure.

Table 3. General summary of tests and results.

| Test name | Number of Repetitions | Results |
|---|---|---|
| System recovery for token loss | 50 | Satisfactory |
| System recovery for ACK loss – UP dropout | 50 | Satisfactory |
| System recovery for change in controlling unit | 50 | Satisfactory |
| System recovery for a disturbed medium | 50 | Satisfactory |

Table 4. Numerical summary of tests and results.

| Test name | Number of Repetitions | Average Time |
|---|---|---|
| System recovery for token loss | 50 | 30 s |
| System recovery for ACK loss – UP dropout | 50 | 18 s |
| System recovery for change in controlling unit | 50 | 149 s |
| System recovery for a disturbed medium | 50 | 212 s |

Table 5 shows the summary of the above presented results, including the reduction in the recovery time (as a percentage) between manual recovery (whose data was taken prior to the beginning of this project and the implemented automatic recovery.

## System reliability

According to the specifications in *Applied R&M Manual for Defense Systems Part D - Supporting*

Table 5. Average recovery time comparison per failure type.

| FAILURE | AVERAGE RECOVERY TIME | | | TIME REDUCTION (%) |
|---|---|---|---|---|
| | MANUAL | AUTOMÁTIC - SIMULATED | AUTOMÁTIC - IMPLEMENTED | |
| Token loss – Fall of the PU | 87 s | 29.9 s | 30 s | 0,2192 |
| ACK loss – Fall of a UP | 65 s | 18.34 s | 18 s | 0,1963 |
| Fall of the Controller Unit | 354 s | 150.4 s | 149 s | 0,2192 |
| Disturbed media | 458 s | 210.14 s | 212 s | 0,2150 |

*Theory, section 2.6 (page 3)*[2], system reliability does not have a unique measurement procedure or criteria, but it can be compared to its availability.

The authors of the article named *Measuring Software Reliaibity in Practice: An Industrial Case Study*[3]*, section 2.3 "Measurement and tracking practices"*, support this statement by indicating that "three (03) parameters may guide service availability/reliability measurements: failure rate (mean time to failure – MTTF), Failure coverage (for the case of hardware components – probability of detecting and correcting a hardware failure), and mean recovery time – MTTR" *(Benlarbi and Storte, 2007).*

Generally, in a simplified manner, the reliability of a system may be measured by the mean time between failures MTBF or MTTF, as indicated by companies such as EventHelix[4] and Vinci Consulting[5], which use system availability measurements to refer to reliability.

An intuitive way to measure system reliability/availability is by measuring the time the system is out of service.

During the initial testing stage of the Data Link system under study, the perspective of EventHelix was used to determine its reliability (when failure event recoveries were manual). In order to preserve the same measurement reference and to make valid comparisons, table 16 was also used, which has the values used by said company to measure the Data Link system reliability/availability, including the automatic failure recovery mechanisms.

The validity of the information provided by EventHelix was confirmed by comparing the data shown in Table 6 with the one provided by IBM for the same type of measurement. The availability/reliability matrix supplied by IBM[6] was extracted from their RedBook "*IBM High Availability Solution for IBM FileNet P8 System*".

Table 6. Reliability/availability of a system according to system downtime[7].

| Availability/Reliability | Downtime |
|---|---|
| 90% (1-nine) | 36.5 days/year |
| 99% (2-nines) | 3.65 days/year |
| 99.9% (3-nines) | 8.76 hours/year |
| 99.99% (4-nines) | 52 minutes/year |
| 99.999% (5-nines) | 5 minutes/year |
| 99.9999% (6-nines) | 31 seconds/year |

The comparison allowed for confirmation that EventHelix uses valid information to perform its measurements, since its variations do not exceed

2 Online document, available at: http://www.sars.org.uk/old-site-archive/BOK/Applied%20R&M%20Manual%20for%20Defence%20Systems%20(GR-77)/p4c06.pdf

3 Taken from the IEEE database. Drafted by officials of the Alcatel-Lucent – IP Division.

4 Online article, available at: http://www.eventhelix.com/realtimemantra/faulthandling/system_reliability_availability.htm#.VOiMnPmG9e8

5 Online article, available at: http://vinciconsulting.com/blog/-/blogs/%E2%80%9Cthe-table-of-nines%E2%80%9D-and-high-availability

6 IBM. High Availability Solution for IBM FileNet P8 System. Online book, available at: http://www.redbooks.ibm.com/redbooks/pdfs/sg247700.pdf

7 Fuente: EventHelix. http://www.eventhelix.com/realtimemantra/faulthandling/reliability_availability_basics.htm#.VOiORPmG9e8

3% as compared to the information supplied by IBM.

After validating the reference information for the specific reliability measurement experiment for the system under study, two continuous assessment periods of three (03) months (equivalent to 2160 hours) were considered.

Table 7 shows the conversion information used for periods of less than one year, equivalent to the data contained in Table 6.

Table 7. Reliability/availability of a system – system downtime equivalence.

| | Downtime | | | |
|---|---|---|---|---|
| **Availability/Reliability** | **Year** | **Month** | **Week** | **Day** |
| 90% (1-nine) | 36.5 days | 3 days | 16.8 hours | 2.4 hours |
| 99% (2-nines) | 3.65 days | 7.2 hours | 1.68 hours | 14.4 mins |
| 99.9% (3-nines) | 8.76 hours | 43.2 mins | 10.08 mins | 1.44 mins |
| 99.99% (4-nines) | 52 mins | 4.33 mins | 60.48 sec | 8.64 sec |
| 99.999% (5-nines) | 5 mins | 25.9 sec | 6.04 sec | 864 ms |
| 99.9999% (6-nines) | 31 sec | 2.59 sec | 604.8 ms | 86.4 ms |

Table 8 was drawn from the information gathered during the three (03) months of testing, which summarizes the measured “downtimes”. These values correspond to the average obtained during the testing period.

The measurements taken correspond to two conditions: manual recovery mode (data gathered between June - September, 2012) and the implemented automatic recovery mode (data collected between October 2014 – January 2015).

Table 8. Reliability/availability of the system under study.

| Condition | Downtime | Reliability/availability |
|---|---|---|
| Manual Recovery | 260500 seconds/month = 72.36 hours/month = 3 days/month | 90% |
| Implemented Automatic Recovery | 26118 seconds/month = 7.25 hours/month | 99% |

In general, four (04) types of failures were detected in the system under study. 50% of the failures detected were due to Token loss, whether because the NCS or the CU lost connection or because a PU left the network while holding the token. The other 50% of the failures was distributed as follows: 25% due to PU disconnections and 25% due to external factors (electronic warfare techniques).

75% of the failures detected in the system are a result of dead states in the system, while the remaining 25% are due to external factors. In the naval operating environment, direct energy radiation is the most commonly used electronic warfare technique (external factor – from the operating environment).

With the implementation of the automatic failure recovery system, the following can be affirmed:

- Upon comparison of the data obtained in the tests ran in the system for manual recovery vs the data obtained from the tests ran in the system for automatic recovery case, we found a 61.75% reduction in the system’s failure recovery time, going from an average recovery time of 241 seconds to an average of 102.25 seconds.

- We were able to increase the reliability of the data link system under study by 9%. The 61.75% average reduction in recovery times allowed the reliability of the system to increase from 90% (equivalent to 72.35 hours/month in which the system was down), to 99%

(equivalent to 7.25 hours/month in which the system was down).

- Human/manual intervention in the system recovery process increases recovery times by 53-72% and therefore, reduces system reliability. The worst case being a "Fall of a PU – ACK loss", where the time increases from 18 seconds to 65 seconds.

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# Analysis of Operational and Seakeeping aspects in the Design of PSV type for the Colombian Caribbean Sea

Análisis de los aspectos operacionales y de comportamiento en olas en el diseño de embarcaciones de apoyo tipo PSV para el Caribe Colombiano

Jairo H. Cabrera [1]
Cinthya Marcela Medina [2]

## Abstract

Colombia is currently searching for oil and gas at sea as new exploratory frontiers so as to incorporate new reserves. With the beginning of maritime operations comes the need for large offshore structures that allow the extraction and separation of oil and gas before transporting it to land. Most of these platforms require specific support and supply vessels, carrying a variety of loads, from liquid and bulk up general cargo, and various specific activities such as towing, rescue staff in case of accidents, firefighting and positioning anchor handling. In the offshore industry, these are known as PSV (Platform Supply Vessels). The main purpose of this work is the hydrodynamic PSV considering the environmental and operational conditions of the Colombian Caribbean including a case study.

**Key words:** Offshore Operations, Seeakeeping, PSV.

## Resumen

Actualmente Colombia está buscando petróleo y gas en el mar así como nuevas fronteras exploratorias para incorporar nuevas reservas. Con el inicio de las operaciones marítimas se presenta la necesidad de grandes estructuras costa afuera que permitan la extracción y separación de petróleo y gas antes de transportarse a tierra. La mayoría de estas plataformas requieren buques de apoyo y aprovisionamiento específicos, llevando una variedad de cargas, desde líquidos hasta grandes cargas generales, y varias actividades específicas tales como remolcar, rescatar trabajadores en caso de accidentes, maniobras contraincendios y de posicionamiento de anclas. En la industria costa afuera, se conocen como buques de apoyo a plataforma (PSV: Platform Supply Vessel). El objetivo principal de este trabajo es considerar la hidrodinámica del buque considerando las condiciones ambientales y operacionales del caribe colombiano.

**Palabras claves:** operaciones costa afuera, comportamiento en el mar, buques de apoyo a plataforma.

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## Introduction

Colombia is becoming a leader in crude oil production in South America, growing at above 10% rates, more than Brazil. Colombia currently holds the third place in the region, climbing up the ranks from the fifth place since 2005, to its current position [10].

The hydrocarbon sector has been the spearhead of the country's Government strategy, shifting from US$ 277 million in foreign investment in 2003, to US$ 263 million in 2009. This sector is undertaking an aggressive plan to explore and produce, focusing on increasing the largest index of utilization of the current reservoirs, increasing the transportation infrastructure to accelerate the production in the new findings, and increasing its presence in the Caribbean with recent offshore exploration contracts [10].

Facts and numbers show that the oil activity has its engines running and that Colombia is increasingly attractive for foreign investment in the Latin American area. The spike in drillings is largely due to the leadership assumed by the oil sector. Colombia produces a little less than one million daily barrels, but it has a potential of 47 billion barrels in its reserves. It is noteworthy that the depths of the Caribbean are focusing the attention of companies such as Ecopetrol, Exxon Mobil and Petrobras [9].

Colombian Caribbean Sea is one of the main targets of the companies in the oil sector, and therefore various studies must be made regarding the support services that these new offshore infrastructure will demand.

With the beginning of maritime operations comes the need for large offshore structures that allow the extraction and separation of oil and gas before transporting it to land. Most of these platforms require specific support and supply vessels, carrying a variety of loads, from liquid and bulk up general cargo, and various specific activities such as towing, rescue staff in case of accidents, firefighting and positioning anchor handling [17].

The design of this type of vessels must consider the special characteristics of the maritime conditions of the operating regions or exploration blocks through a spectral analysis. The main purpose of this work is to analyze the behavior at sea of support vessels that adapt to the particular wave conditions of a specific location from the Caribbean Colombian Sea.

## Analysis models

### Ocean-Wave Spectra

The models for analyzing the behavior of vessels at sea is initially based on the vessel behavior represented by its RAO's and the Ocean-wave spectral crossing considering random seas, representing by the probabilistic model from equation 1.

$$m_n = \int_0^\infty \omega^n \cdot S(\omega) \cdot d\,\omega \qquad (1)$$

The zero order spectral moment $m_0$, equation 2, is of vital relevance and it is equivalent to the area under the curve of the wave spectrum, which accounts for the variance of the time series of the evaluated waves.

$$m_0 = \int_0^\infty S_\zeta(\omega)\, d\,\omega \qquad (2)$$

The standard deviation and up-zero Crossing are given by equation 3 y 4 as below.

$$\sigma = \sqrt{m_0} \qquad (3)$$

$$T_z = 2 \cdot \pi \cdot \sqrt{\frac{m_0}{m_2}} \qquad (4)$$

Mean Period, can be found to calculate the center of the area of the energy spectrum, and it is given by equation 5.

$$T_M = 2 \cdot \pi \cdot \frac{m_0}{m_1} \qquad (5)$$

Significant wave height $H_s$, equation 5, represents the mean of the upper third of the highest ocean heights.

$$H_s = 4 \cdot \sigma = 4 \cdot \sqrt{m_0} \qquad (6)$$

There are different analytic models to analyze the ocean-wave spectra. The next step is the correct selection of wave spectrum for a particular seaway. Reviews of the main models are show below.

***Neumann Spectrum [11]:***

$$S(\omega) = \frac{AR}{\omega^6} e^{\frac{B}{\omega^2}} \qquad (7)$$

Where $A$ and $B$ depend on the wind speed $V_w$.

***Pierson-Moskowitz Spectrum [16]:***

$$S(\omega) = \frac{8{,}1 \times 10^{-3} g^2}{\omega^5} e^{-0{,}74\left(\frac{g}{V \times \omega}\right)^4} \qquad (8)$$

Where:
$w$ is the circular frequency of the waves
$V_W$ is the wind speed.

***ITTC Spectrum [14]:***

$$S(\omega) = \frac{8{,}1 \times 10^{-3} g^2}{\omega^5} e^{\frac{-\left(\frac{3{,}11}{h_{1/3}^{-2}}\right)^4}{\omega^4}} \qquad (9)$$

The only available information used is: $H_{1/3}$;

***Bretschneider Spectrum [1]:***

$$S(\omega) = \frac{\left[\frac{172{,}75\, h_{1/3}^{-2}}{T_1^4}\right]}{\omega^5} e^{\left(\frac{691}{T_1^4}\right)} \qquad (10)$$

It is used when the height and period information are available.

***JONSWAP Spectrum [8]:***

$$S_j(\omega) = 0{,}658 \times C \times S_B(\omega) \qquad (11)$$

This criteria is used in places where the wave formation region is a constraining factor for wave generation, it is a variation of the Bretschneider spectrum [1].

### Seakeeping Analysis

Seakeeping ability measure of how well suit a vessel is to condition when underway. It also refers to the analyzing the behavior of a vessel in regular waves, representing through the RAOs (Response Amplitude Operator). RAO is a linear operator that represents the input (wave) – output (movement) transfer, it being of key relevance to determine vessel design parameters.

The RAO describes how the response of the vessel changes with frequency variations. The Fig. 1 (page 50) shows a classic example of a RAO response representing the Heave and Pitch amplitudes from PSV Case study.

We can see how RAO approaches one for low frequencies and it is when the vessel shifts up and down with the wave, acting as a cork. For high frequencies, the response approaches zero while the effect of many short waves in cancelled along the vessel's length. Normally, the vessel would also have a peak higher than one, which occurs close to the natural period of vessels. The peak is due to resonance. A RAO above one indicates that the vessel's response is higher than the amplitude of the wave (or than the slope).

### Spectral Crossing

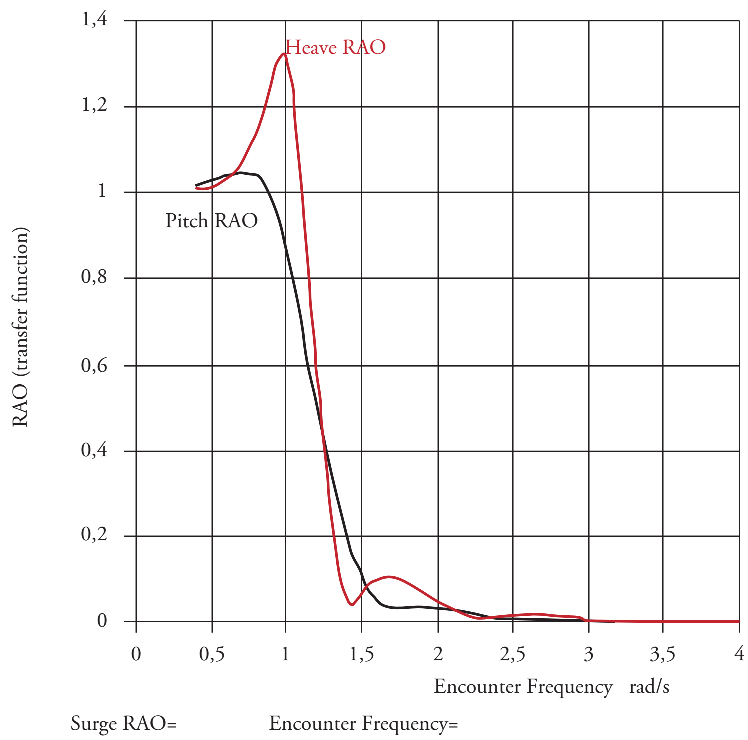
It is the product of the Sea spectrum times the transference function (RAO), Response Amplitude Operator, according equation 12, below.

$$S_z(\omega) = [RAO]^2 \cdot S(\omega) \qquad (12)$$

## Seakeeping Criteria

In order to analyze the seakeeping behavior of PSV, we must consider the following criteria, known in literature as events:

Fig. 1. RAO PSV Response Example case (10 knots – 180º).




- Water on deck
- The hydrodynamic impact, or Slamming
- Accelerations on the main deck and quarters
- Propeller emersion

In accordance with these analysis, we chose six different points along the hull of the vessel deemed as critical and where the events were to be analyzed.

The locations are:

P1 – Bow (Forecastle)
P2 – Bow (Forefoot)
P3 - Propeller
P4 - Stern
P5 – Upper deck
P6 - Superstructure

Fig. 2. Critical PSV locations.

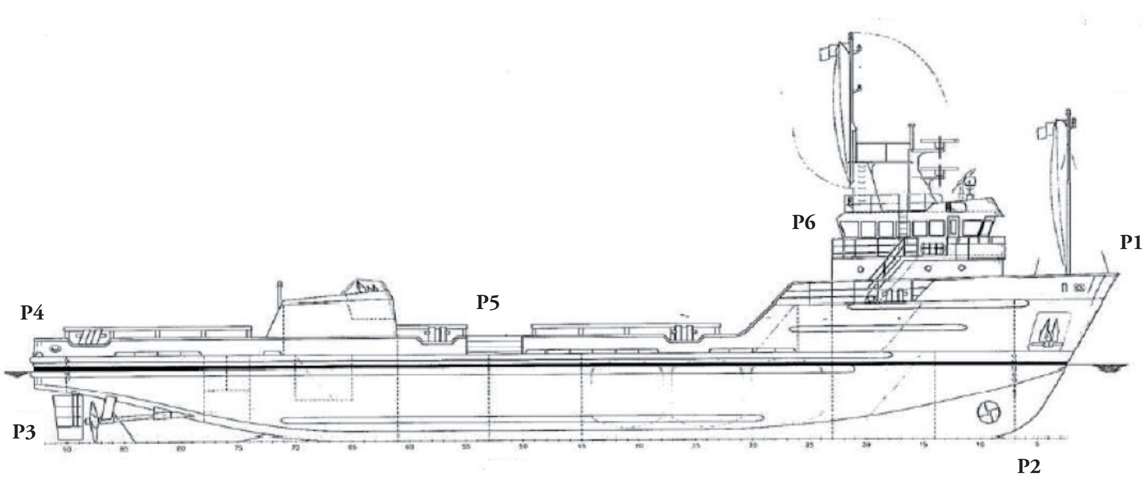


Fig. 2 shows the identification of these critical points on the hull of a PSV type vessel.

Motion Analysis program based on "Strip Theory" was used to analyze the various events on the behavior of the vessel at sea, where each transverse section of the ship resembles a polynomial in relation to the cylindrical shape of the hull. This theory applies to slim vessels and it is assumed that the presence of the hull does not affect the incidence of the wave on the hull.

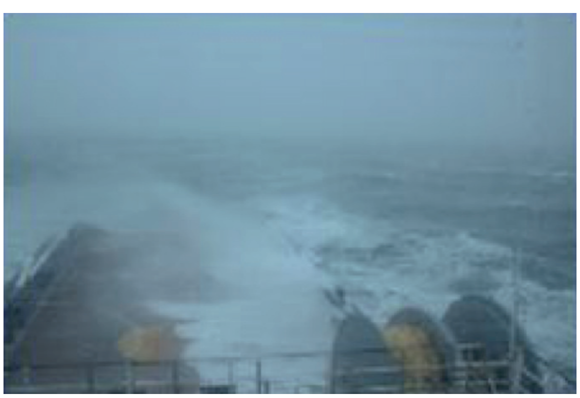
## Water on deck

Water on deck occurs when the movement of the vessel due to the water level exceeds the hull depth that exerts a load on the deck due to a mass of water exceeding the depth. Fig. 3 show a example for this phenomenon.

For the case of the design of an offshore support vessel, this analysis becomes even more important due to the movement of the load and the crew on the deck.

The predefined limit for water occurrence on the deck is 5%. However, in the case of support vessels, water deck is a common event. In this case, the vessel shall be designed for the least occurrence and to ensure the safety of the crew that performs tasks on exposed decks. The probability of this event occurring is representing by equation 13.

Fig. 3. Water on deck.



$$P_{gw} = exp\left[-\frac{h^2}{2m_{0mn}}\right] \quad (13)$$

Where:
*h* as the effective freeboard height
$m_0$ as the variation of the vertical relative displacement spectrum.

## Hydrodynamic impact

The hydrodynamic impact, known as *slamming*, occurs when the combination of displacement and vertical speed is strong enough so that the combined *pitch* and *heave* response is amplified, causing an impact when the bow enters the water as show Fig. 4.

Fig. 4. Hydrodynamic impact.

The information obtained regarding this event is:

- Frequency of appearance of the hydrodynamic impacts;
- Time interval between impacts;
- Impact strength;
- Vessel speed at which damage to the hull may occur.

Equation 14 representing the probability of this event occurring and must not exceed 1%.

$$P_s = exp\left[-\frac{t^2}{2m_{0rvm}}\right] x\ exp\left[-\frac{v^2}{2m_{0rvv}}\right] \quad (14)$$

where,
*t* is draught in the mid section;
*s* is the wave length coefficient 5,00 according to Bhattacharyya [2]
$m_{0rvm}$ is the variation f the vertical movement in relation to the bow spectrum.

$m_{0rvv}$ is the Variation of the bow vertical speed spectrum.
$v_c$ is the critical speed deducted by Ochi, m/s.

## Accelerations on the Main Deck and Quarters

Accelerations must be verified in these locations to prevent exceeding an acceleration that may affect the wellbeing of the crew.

There are some ocean conditions in which the crew may become exposed to uncomfortable situations that have an impact on the performance of their duties.

The intensity of accelerations for different locations of interest is determined by the equation 15, below.

$$\ddot{Z}_{1/10} = 2{,}55\sqrt{m_{0z}}\,(1-\varepsilon^2)^{1/2} \tag{15}$$

where:
$m_{0z}$ = area under the response spectrum for vertical acceleration
$\sqrt{(m_{0z})}$ = RMS
$\varepsilon = 0{,}6$
$\ddot{Z}_{1/10}$ = shaw not exceed 0,5g (4,905m/s$^2$)

For the case of passenger vessels, assessing comfort in sailing is of vital importance, and it may be expressed as the percentage of passengers becoming seasick in agitated waters. Lateral and vertical acceleration are the main causes of dizziness. [6], [7], [12].

Table 1 shows a vertical RMS acceleration scale that may be used to estimate the maximum acceptable magnitude for different on-board activities and for the crew and passenger comfort.

Table 2 lists typical criteria for the performance of a battleship crew. These criteria are presented as having significant amplitude, which is the mean of a third of the highest amplitudes and is close to what a trained observer could estimate.

The *Motion Sickness Indicator* (MSI) concept was developed in a study sponsored by the United States Navy in the 1970s, to investigate the effects on humans of vessel motion *(O'Hanlon and McCauley, 1974)* [13]. The research sough to qualify the incidence of motion sickness in a group of over 500 people exposed to different amplitudes and frequencies of vertical movement. The RMS acceleration and the frequency ranged between 0.27 to 5.5 m/s$^2$ and 0.083 to 0.700 Hz, respectively.

The experiments showed that motion sickness onset correlated to the acceleration and frequency, thus yielding a motion sickness indicator from said data. The MSI value indicates the percentage of persons who experienced motion sickness in a 2h testing period. According to the test data, people have significantly less tolerance to vertical movement between 0.2 and 0.16 Hz (5-6 s), range from higher to lower frequencies.

Table 1. Vertical acceleration limit criteria.

| RMS Vert. Accel. (g) | Description |
|---|---|
| 0,02 | Passengers on a cruise. Elders. If close to the lower limit, dizziness is unlikely. |
| 0,05 | Passengers on a ferry boat. International standard for 2 hours of exposure to the period. Causes of dizziness movements in about 10% of non-acclimated adults. |
| 0,100 | Intellectual work for persons reasonably accustomed to boat movements. Demanding cognitive/manual work. Long term tolerable for the crew. The international standard for one half hour of an exposition term. |
| 0,150 | Hard work for people adapted to the movements of a vessel: for example, fishing vessels and supply vessels. |
| 0,200 | Light work for people adapted to the movements of a vessel. Not tolerable for long periods. Quickly causes fatigue. |
| 0,275 | Simple tasks. Most of the attention is focused on keeping balance. Tolerable only during short terms on high speed vessels. |

Table 2. Typical staff performance criteria for a vessel.

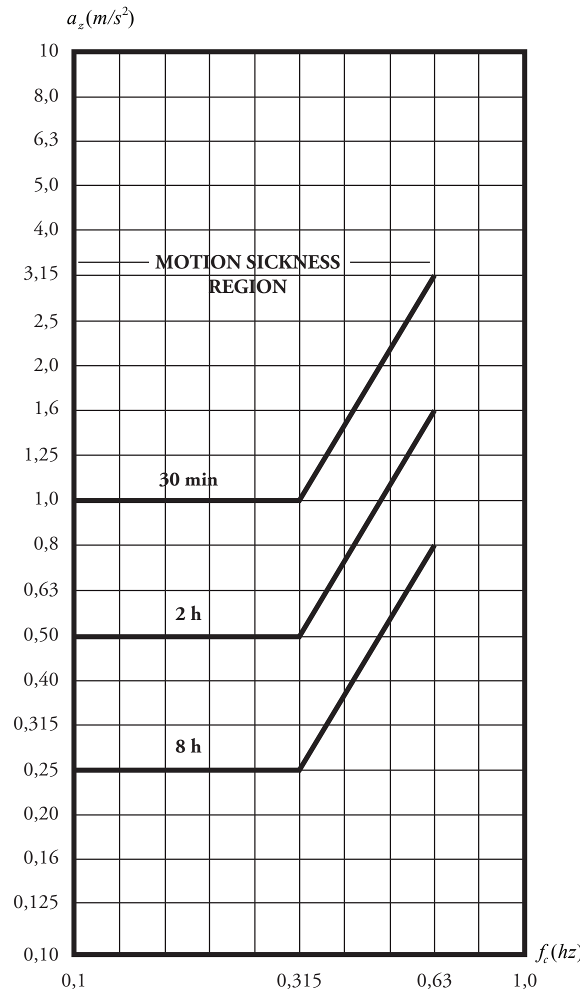
| Application | Movements | Limits | Location |
|---|---|---|---|
| **General** | Vertical acceleration | 0,4 g | Bridge |
| | Lateral acceleration | 0,2 g | Bridge |
| **Specific tasks** | MSI | 20% of the personnel | Task placement |

The main source of criteria on the incidence of motion sickness is International Standard ISO 2631 (ISO 2631-3, 1985) [12]. This standard covers vertical vibration from 0.1 to 0.63 Hz frequency range and links the vertical acceleration, and frequency factors, and offers limits severe discomfort in terms of the RMS vertical acceleration for different exposure times, as shown in Fig. 6.

The data field indicates that around 10% of the passengers will show motion sickness symptoms when RMS acceleration is 0.5 $m/s^2$ (approximately 0.05 g significant), which is also the ISO limit for a period of a two hour exposure in the 0.1 to 0.315 Hz range.

As Fig. 5 shows, depending on exposure time and oscillation frequency, several RMS vertical acceleration values could be selected as criteria for behavior at sea. This would yield different levels of habitability for the same water conditions.

Fig. 5. ISO 2631. Severe sickness limits. [12].




### Propeller emersion

The purpose of this event is to identify the probability of propeller emersion, which should be limited to a 5% occurrence. A great risk for the vessel arises when it enters severe ocean conditions and the propeller emerges, since this causes an excess load on the bearings and coupling gears of the engine.

Using the Rayleigh distribution we can obtain the probability of propeller emersion occurring in some wave incidence conditions, according equation 16, below.

$$P_{PE} = exp\left[-\frac{h^2}{2m_{0rvm}}\right] \quad (16)$$

Where,
$h$ is depth in the upper part of the propeller
$m_{0rvm}$ is the variation of the stern spectrum relative vertical motion.

## Environmental condition

According information to the CIOH [3], there are four areas in the Caribbean Sea with meteoceanographic and weather information for the naval community and in order to generate forecasts, to wit: northwest, southwest, northeast, and southeast. The current area with the largest exploration potential is the southwest, which presents the most severe wind and wave conditions of all this sector. In said area, wave heights range from 2 to 2.7 m according to the forecast bulletins issued by the CIOH [3], the wind came from the northeast at 23-25 knots, the time of the year chosen as an example is January, which represents an extreme condition for such region.

For the extreme Caribbean conditions, we will consider the data gathered during hurricane Emily in 2005, since it brought 7 meter waves with 16 second periods, 400 meter wavelengths, a phase speed of 25.18 meters per second (48.94 knots), and group speeds close to 13 meters per second (25.26 knots). The predominant direction of the waves in this part is due north, ranging between NW and NE (330°-030) [4].

Considering the above characteristics of the waves for the Caribbean region, we will choose two conditions to analyze in accordance with one for normal conditions where the wave heights will range between 2 and 2.7 m and a second one for extreme conditions, where the waves will be 7 m high, resembling a hurricane. The selected spectrum is JONSWAP, adjusted to those ocean conditions, data detailed in table 3.

Table 3.Environmental conditions.

| Condition | Hs (m) | Tp (s) | Wind Speed (knows) | Incidence | Spectrum |
|---|---|---|---|---|---|
| **Normal** | 2-2.7 | 8.5 | 23-25 | NE | JONSWAP |
| **Extreme** | 10 | 16 | 48.94 | NW-NE | JONSWAP |

## Case Study

Due to the development seen in the country's oil industry, and the imminent investment of the large oil companies and drilling in offshore reservoirs in the Caribbean, we decided to focus this analysis on the design of a vessel to provide logistics support to offshore operations (PSV)., as shown in Fig. 6.

Fig. 6 shows the basic PSV hull geometry and table 4 the main dimensions. The vessel will undergo the sea behavior analysis in the Caribbean, in accordance with the defined environmental conditions.

Fig. 6. PSV Case Study.

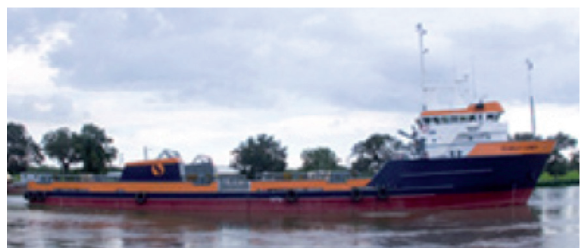


Fig. 7. RAO (Speed 10 knots – 135º).

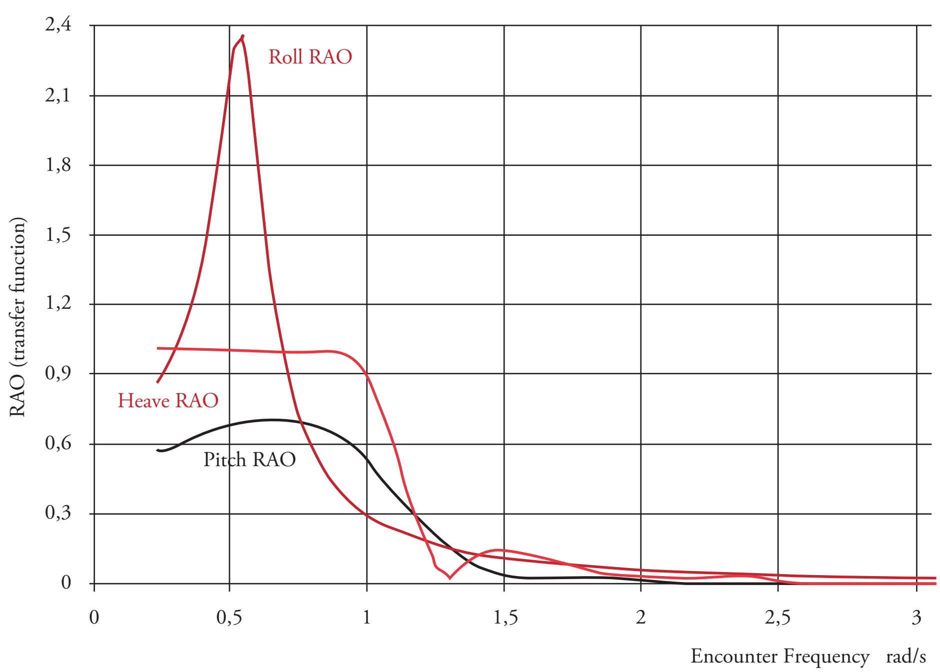



Fig. 7 shows the RAO for heave, pitch, and roll for a speed of 10 knots and a 135° angle when meeting the waves.

Seakeeping criteria were analyzed from normal and extreme environmental of Caribbean Sea condition. Tables from 5 to 17 below are the

Table 4.PSV Main dimensions.

| Name | Dimensions (m) |
|---|---|
| Length, LBP | 68 |
| Breadth, BOA | 20 |
| Draught | 6 |
| Depth | 8 |

results of the verifications of probability events for 0 and 10 knots, and 180°, 135°, 90°, 45°, and 0 incidences.

MSI results according Fig. 8 are expressed in terms of the level of acceleration causing motion sickness to 10% of the people on board during a specific time interval.

Table 5. Probability of accelerations in normal conditions at speed 0.

| Probability | | | | | |
|---|---|---|---|---|---|
| **Location** | **135°** | **90°** | **45°** | **180°** | **Criteria < 0,5g** |
| **P1. Bow (forecastle)** | 1.79 | 1.69 | 2.15 | 2.25 | |
| **P2. Bow (Forefoot)** | 1.68 | 1.69 | 2.06 | 2.10 | 4.905 |
| **P3. Propeller** | 1.43 | 1.60 | 2.05 | 1.25 | |

Table 6. Probability of accelerations in normal conditions at speed 0.

| Location | 135° | 90° | 45° | 180° | Criteria < 0,5g |
|---|---|---|---|---|---|
| **P1. Bow (forecastle)** | 1.36 | 1.07 | 1.88 | 1.80 | |
| **P2. Bow (Forefoot)** | 1.23 | 1.07 | 1.75 | 1.66 | 4.905 |
| **P3. Propeller** | 0.95 | 0.95 | 1.69 | 0.81 | |

Table 7. Probability of accelerations in normal conditions at speed 10.

| Probability | | | | | |
|---|---|---|---|---|---|
| **Location** | **135°** | **90°** | **45°** | **180°** | **Criteria < 0,5g** |
| **P1. Bow (forecastle)** | 4.08 | 1.71 | 0.81 | 5.34 | |
| **P2. Bow (Forefoot)** | 3.97 | 1.71 | 0.76 | 5.23 | 4.905 |
| **P3. Propeller** | 3.53 | 1.60 | 0.74 | 4.11 | |

Table 8. Probability of accelerations in normal conditions at speed 10.

| Location | 135° | 90° | 45° | 180° | Criteria < 0,5g |
|---|---|---|---|---|---|
| **P1. Bow (forecastle)** | 1.94 | 0.81 | 0.65 | 4.38 | |
| **P2. Bow (Forefoot)** | 1.84 | 0.80 | 0.62 | 4.24 | 4.905 |
| **P3. Propeller** | 1.51 | 0.84 | 0.53 | 3.15 | |

Table 9. Probability of water on deck in normal conditions at speed 0.

| Probability | | | | | |
|---|---|---|---|---|---|
| **Location** | **135°** | **90°** | **45°** | **180°** | **Limit** |
| **P1. Bow (forecastle)** | 0.26 | 0.02 | 0.60 | 0.58 | |
| **P5. Main deck** | 0.00 | 0.00 | 0.00 | 0.01 | 5% |
| **P4. Stern** | 0.00 | 0.06 | 0.54 | 0.03 | |

Table 10. Probability of water on deck in extreme conditions at speed 0.

| | | | | | |
|---|---|---|---|---|---|
| **P1. Bow (forecastle)** | 0.29 | 0.23 | 0.81 | 0.57 | 5% |
| **P5. Main deck** | 0.09 | 0.25 | 0.06 | 0.00 | |
| **P4. Stern** | 0.00 | 0.27 | 0.80 | 0.04 | |

Table 11. Probability of water on deck in normal conditions at speed 10.

| **Probability** | | | | | |
|---|---|---|---|---|---|
| **Location** | **135°** | **90°** | **45°** | **180°** | **Limit** |
| **P1. Bow (forecastle)** | 0.48 | 0.04 | 0.57 | 0.70 | 5% |
| **P5. Main deck** | 0.01 | 0.01 | 0.30 | 0.10 | |
| **P4. Stern** | 0.01 | 0.04 | 0.42 | 0.02 | |

Table 12. Probability of water on deck in extreme conditions at speed 10.

| | | | | | |
|---|---|---|---|---|---|
| **P1. Bow (forecastle)** | 0.48 | 0.11 | 0.80 | 0.68 | 5% |
| **P5. Main deck** | 0.09 | 0.24 | 0.24 | 0.03 | |
| **P4. Stern** | 0.00 | 0.03 | 0.73 | 0.02 | |

Table 13. Probability of propeller emersion in normal condition at speed 0.

| | **Probability** | | | | |
|---|---|---|---|---|---|
| **Environmental conditions** | **135°** | **90°** | **45°** | **180°** | **Limit** |
| **Normal condition** | 0.00 | 0.00 | 0.08 | 0.00 | 5% |
| **Extreme condition** | 0.00 | 0.00 | 0.10 | 0.00 | |

Table 14. Probability of propeller emersion in normal condition at speed 10.

| | **Probability** | | | | |
|---|---|---|---|---|---|
| **Environmental conditions** | **135°** | **90°** | **45°** | **180°** | **Limit** |
| **Normal condition** | 0.01 | 0.00 | 0.00 | 0.02 | 5% |
| **Extreme condition** | 0.00 | 0.00 | 0.00 | 0.00 | |

Table 15. Probability of hydrodynamic impact in normal condition at speed 0.

| **Probability** | **135°** | **90°** | **45°** | **180°** | **Limit** |
|---|---|---|---|---|---|
| **Bow** | 0.00 | 0.00 | 0.00 | 0.00 | 1% |

Table 16. Probability of hydrodynamic impact in extreme condition at speed 0.

| **Probability** | **135°** | **90°** | **45°** | **180°** | **Limit** |
|---|---|---|---|---|---|
| **Bow** | 0.00 | 0.00 | 0.03 | 0.00 | 1% |

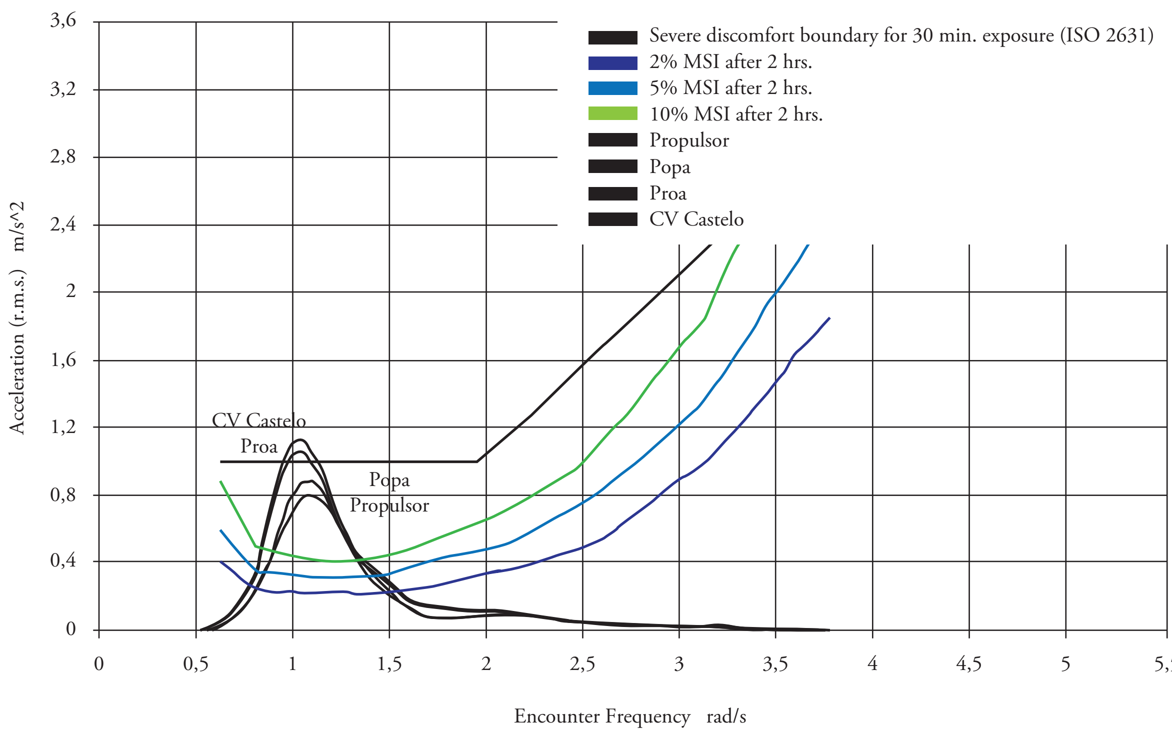
Table 17. Probability of hydrodynamic impact in normal condition at speed 10.

| Probability | 135° | 90° | 45° | 180° | Limit |
|---|---|---|---|---|---|
| Bow | 0.00 | 0.00 | 0.00 | 0.00 | 1% |

Table 18. Probability of hydrodynamic impact in extreme condition at speed 10.

| Probability | 135° | 90° | 45° | 180° | Limit |
|---|---|---|---|---|---|
| Bow | 0.00 | 0.00 | 0.15 | 0.00 | 1% |

Fig. 8. MSI PSV criteria.




## Conclusions

This study defines a series of criteria based on limit values and probabilities, and enables the analysis of the behavior at sea of a PSV type vessel. Each criteria is evaluated for a selected vessel in locations defined as critical at different incidence angles, speeds, and environmental conditions, set as normal and extreme for a region of interest in the Caribbean Sea.

In regards to the results shown, some criteria are not met for the studied vessel. For the accelerations, there are very few values that exceed the limit of the criteria. The values exceeding this limit are found in the forecastle and forefoot at a speed of 10 knots and in a normal environmental condition at a 180° angle. It is noteworthy that the values in these same locations, but in the extreme condition, are close to the limit of the criteria.

The water on deck criteria shows values that exceed the limit in both environmental conditions and speeds. The larges values exceeding this criteria correspond to zero speed and at 90° and 45° angles; in the case of the extreme condition, the angle is 90°. For the 10 knot speed, noncompliance with the criteria is lower, since at those wave heights and vessel speed it is impossible to have no water on the main deck, forecastle bow, and stern.

The probability of propeller emersion shall not exceed 5% and only one condition exceed the criteria, the normal environment condition at zero speed, with a 45° entry angle.

The hydrodynamic impact or slamming shows few times the criteria limit is exceeded, not exceeding 1%, and this is largely reflected in the 45° angle and in the extreme condition for each assessed speed (0 and 10 knots).

Recommendations to modify the design of the hull and internal mass distribution for PSV type vessels, aimed at meeting the criteria presented in this study, will be the subject of future works and development proposals.

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# Structural Design of a Jacket Platform to the Colombian Caribbean Sea

Análisis Estructural de una Plataforma Fija tipo Jacket con Aplicación al Caribe Colombiano

Jairo H. Cabrera [1]
Jair Macía Ávilar [2]

## Abstract

This research paper summarizes the study of the requirements and basic theoretical foundation for the development of structural design of fixed platform type Jacket, resulting in the proposal for a analysis model for this type of offshore structure. Aspects related with cinematics evaluation, selecting of wave theory and hydrodynamic proper formula are also considered in the calculation of acting forces and the need for local metocean data in the analysis. A case study of application of the model for a new type structure jacket RC-5 Block of the Colombian Caribbean is also presented including its geometry proposed and some results of the numerical model procedures.

**Key words:** Jacket Offshore Platform; Structural Analysis and Design.

## Resumen

Este trabajo de investigación resume el estudio de los requerimientos y fundamentos teóricos básicos necesarios para el desarrollo del diseño estructural de una plataforma offshore fija tipo Jacket, resultando en la propuesta de un modelo de análisis propio para este tipo de estructuras. Aspectos relacionados con las evaluaciones cinemáticas, selección de la teoría de ola y de la formulación hidrodinámica adecuada son igualmente considerados en el cálculo de las fuerzas actuantes así como en la necesidad de datos meteomarinos de local de análisis. Un caso estudio de aplicación del modelo para una nueva estructura tipo Jacket en el bloque RC-5 del Caribe Colombiano es igualmente presentado incluyendo geometría propuesta y algunos resultados de los procedimientos numéricos del modelo.

**Palabras claves:** Plataforma Offshore Jacket; Análisis Estructural y Diseño.

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## Introduction

A platform type Jacket is a structure placed on the ocean, built with steel tubular components and fixed at the bottom of the seabed with stakes, used for the exploration and specially for the production of hydrocarbons and mainly for depths of up to 300 meters. Structures that are exposed to the action of the waves, ocean currents, winds, earthquakes and other environmental aspects specific to the site operation and to be considered in the design.

Due to the large demand of hydrocarbons in the world, there is a need to explore new deposits in search for reserves, and consequently, its vast seas are becoming a promising frontier for exploration operations and a source of energy resources, projects known as offshore.

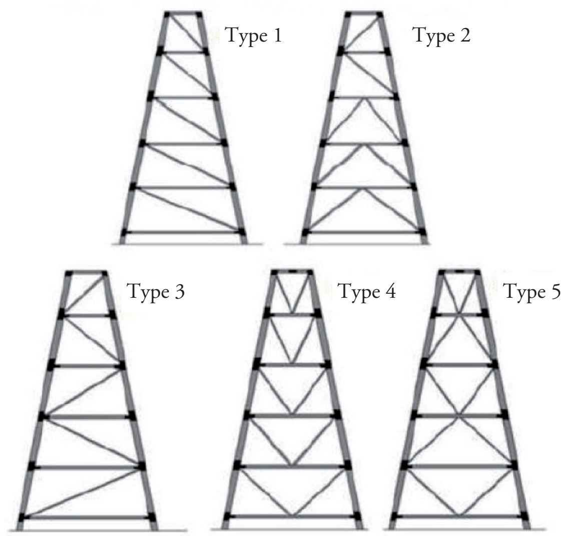
Colombia is not indifferent to these initiatives, since the 2007 Caribbean Round until the last 2014 Colombia Round, a total of 23 offshore contracts have been assigned, of which 21 are in the Colombian Caribbean sea, 13 of them are oriented to the exploration and production of hydrocarbons (ANH).

The main objective of this research paper is to propose a model of analysis in the design of a platform type Jacket offshore considering the characteristics and conditions of loads produced by the environmental effects of the Colombian Caribbean sea. Define the guidelines and basic theoretical foundations to follow in the analysis and design of these types of structures, determining the actions of the environmental loads specific to the region of operation. Establish the procedures and methodologies for analysis and their corresponding design and regulatory criteria for the structures type Jacket with a case study application for the Colombian Caribbean Sea.

## Theoretical Reference

There are various configurations for structural settings for the structures type Jacket depending on their installation and performance with respect to the environmental conditions and particularly to the seismic activities of a specific region, as shown in Fig. 1 [7].

Fig. 1. Structural Configuration [7].




For the analysis of environmental forces on a structure type Jacket, the loads to which the sea based platform is exposed are evaluated. Therefore, the calculations of the environmental forces should not be made based solely on the estimations of the maximum loads on the structure, representing extreme situations like a tsunami, hurricane, earthquakes, storms, etc.; which directly affect the environmental forces increasing them with a factor up to five times the value of the normal operational loads.

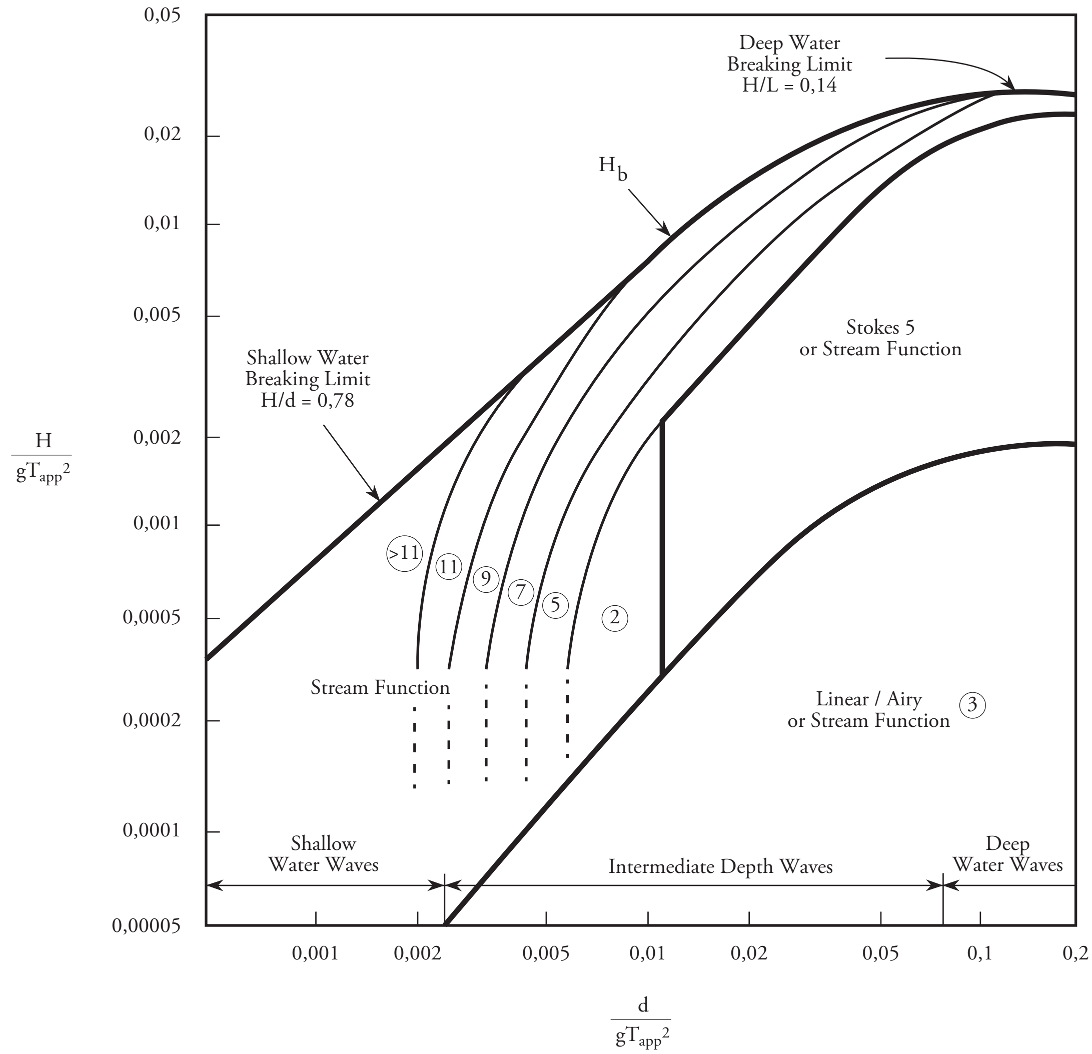
From the point of view of the cinematics of water particles we have bidimensional models that work as a starting point for the estimation of the status of the sea based on the following classic theory of waves [5], among others:

- Stream Function
- Stokes of 5° order.
- Linear wave or Airy

Fig. 2 (figure 2.3.1-3 of section 2 of API RP2A-WSD), shows the regions of application of the theory of waves mentioned in the above list.

The most widely used theory and because of its simplicity is the linear theory of Airy, given that

Fig. 2. Selection of the theory of waves [3].




$H/gT_{app}^2$ : Dimensionless wave steepness H : Wave height d : Mean water depth g : Acceleration of gravity

$d/gT_{app}^2$ : Dimensionless relative depth $H_b$: Breaking wave height $T_{app}$ : Wave period

the origin of his formula is based on the potential of speeds, which depend on the position of the particle in the fluid and the given t that is taken as a reference. See equation 1.

$$Ø\,(z,y,t) = \frac{A*G}{w} * \frac{\cosh K(y+d)}{\sinh\,(K*d)} * \sin K * x - w * t \quad (1)$$

Where:

$A$ = wave width.
$g$ = gravity acceleration.
$w$ = frequency of the wave (rad/s).
$K$ = number of wave.
$d$ = height of sheet of water.

The hydrodynamic forces on the structural elements due to the action of the waves can be estimated in three different forms [2]:

- Morison Equation
- Froude- Krylov Theory
- Diffraction Theory

According to the foregoing, when a structural element has a small relationship between the significant length (being such length the diameter in the case of cylinders) and the length of the wave tide (according Fig. 3), said element does not significantly prevent the propagation of the incident wave, therefore, it is possible to use the Morison equation for the calculation of the hydrodynamic forces on slim cylinders. This is the case in the majority of steel platforms type Jacket, where the structural elements usually do not exceed two meter diameters, against wave lengths that are generally larger than one hundred meters in the design waves.

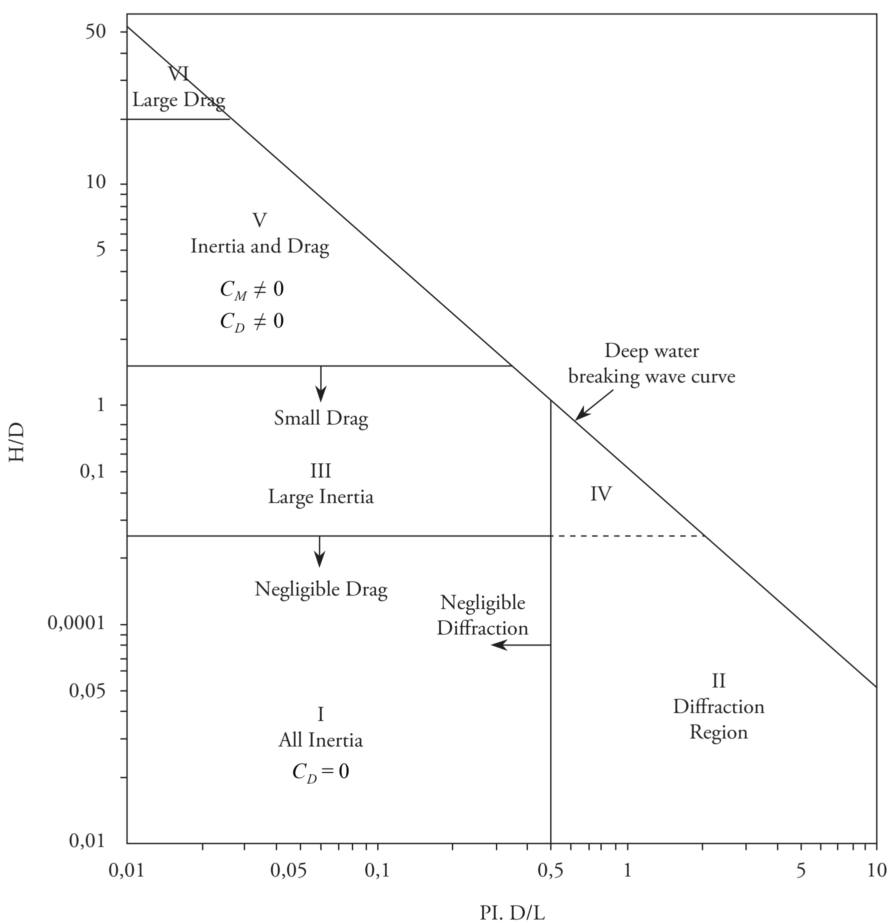
In the Morison Equation, equation 2, the acting force has two components participating simultaneously, the terms of inertia and drag. This calculation can be applied when the structure is small with respect to the length of the tide wave. [2].

$$F = C_D * \rho * \frac{D}{2} * |u| * u + (C_M - 1) * \pi * \rho * \frac{D^2}{4} * \dot{u} + \pi * \rho * \frac{D^2}{4} * u \quad (2)$$

Being that these are the main loads that determine the life cycle of a structure, the models and processes must be studied with detail to determine the limitations produced by each one considering the different codes that seek the design of an optimal structure for different environmental conditions.

In relation to the wind forces, the general expression is used for the calculation of said action over any structure located on the sea, represented by the equation 3.

Fig. 3. Regions to determine the hydrodynamic force formulation theory [3].



$$F_v = C_v * \frac{\rho}{2} * V_v^2 * A_v \quad (3)$$

Where:

$F_v$ = Wind force.
$C_v$ = Wind Coefficient.
$V_v$ = Wind speed.
$A_v$ = Projected area of the surfaces in which it is found

The value of the wind coefficient is represented by a factor of the form of the structure and the factor depending on the height of the affected part of the structure, according equation 4.

$$C_v = C_s * C_h \quad (4)$$

Where:

$C_s$ = Coefficient of Form (see table 1)
$C_h$ = Coefficient of Height (see table 2)

Table 1. Values for Coefficients of Form according to ABS.

| Values for Cs | |
|---|---|
| Form | Value |
| Spheres | 0.4 |
| Cylinder Forms (all sizes) | 0.5 |
| Hull (type of surface) | 1.0 |
| Superstructure | 1.0 |
| Isolated structures (cranes, beams, bridges, tc) | 1.5 |
| Areas under cover (smooth surface) | 1.0 |
| Areas under cover (beam and length) | 1.3 |
| Davit, crane gears (each face) | 1.3 |

In the estimation of the loads by the presence of ocean currents, the classic expression of an immersed element of a floating structure is used, equation 5.

$$F_c = C_d * \frac{\rho_s}{2} * V_v^2 * A_c \quad (5)$$

Where:

$F_c$ = Force of current.
$C_d$ = Drag coefficient.
$A_c$ = Area of the surface that is against the current. ($m^2$).
$V_c$ =Speed of the current.
$\rho_s$= Water density (1,025 - 1,040 $Kg/m^3$).

The tubular components of the Offshore structures type Jacket are designed and verified against the admissible tensions and limit status in accordance with a series of codes applicable to the sector, mainly for these structures of the American Petroleum Institute (API). Codes that not only include resistance and functionality requirements, as well as additional structural behavior aspects plus complexes, such as hydrostatic collapse, punching sheer and resistance to damages from fatigue. The foregoing corresponds to one of the most relevant stages of the design process, providing a reasonable level of reliability during the life cycle provided for the structural components.

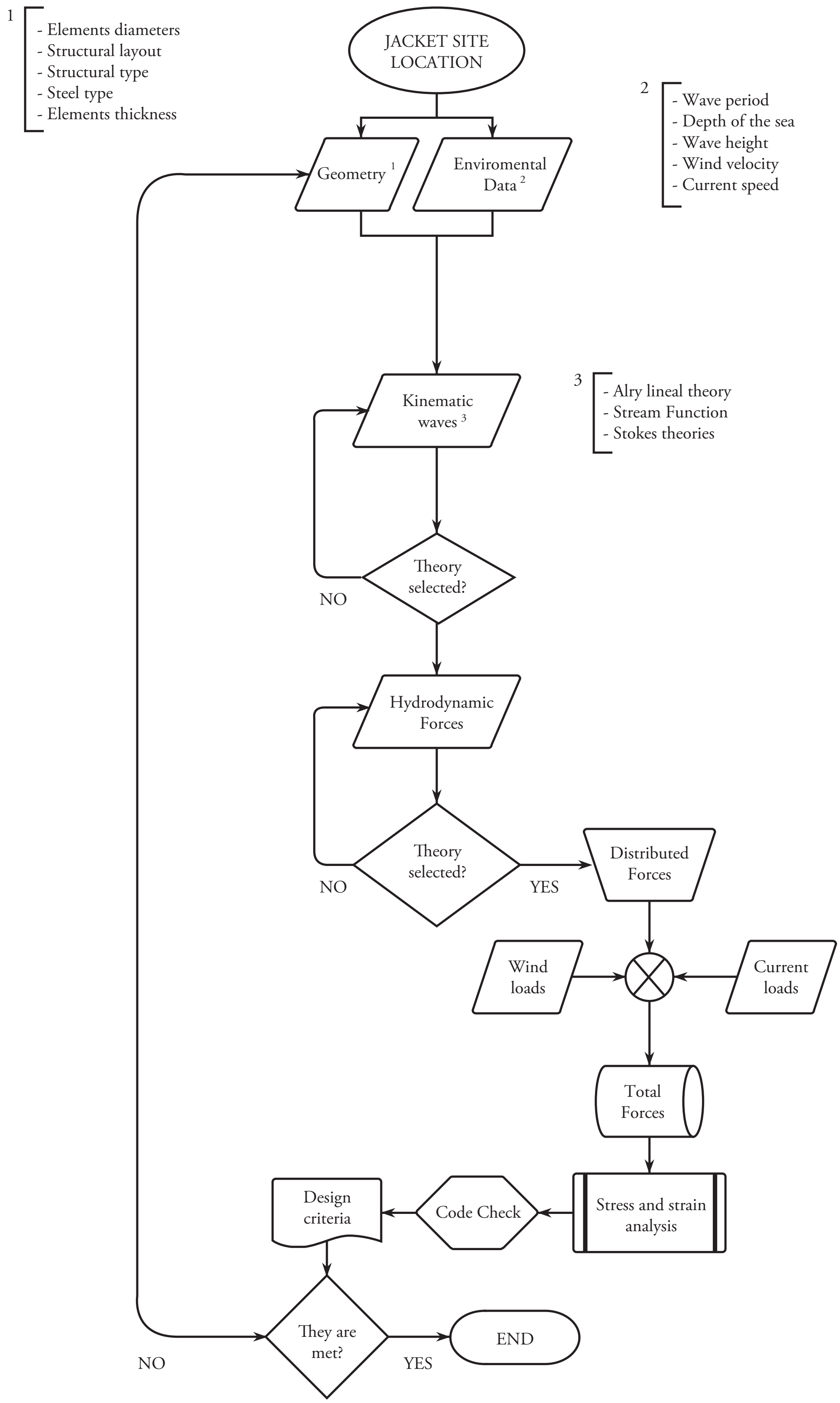
Table 2. Values for correction by height according to ABS.

| Altura (metros) | Altura (pies) | Ch |
|---|---|---|
| 0,0 - 15,3 | 0-50 | 1,00 |
| 15,3 - 30,5 | 50-100 | 1,10 |
| 30,5 - 46,0 | 100-150 | 1,20 |
| 46,0 - 61,0 | 150-200 | 1,30 |
| 61,0 - 76,0 | 200-250 | 1,37 |
| 76,0 - 91,5 | 250-300 | 1,43 |
| 91,5 - 106,5 | 300-350 | 1,48 |
| 106,5 - 122,0 | 350-400 | 1,52 |
| 122,0 - 137,0 | 400-450 | 1,56 |
| 137,0 - 152,5 | 450-500 | 1,60 |
| 152,5 - 167,5 | 500-550 | 1,63 |
| 167,5 - 183,0 | 550-600 | 1,67 |
| 183,0 - 198,0 | 600-650 | 1,70 |
| 198,0 - 213,5 | 650-700 | 1,72 |
| 213,5 - 228,5 | 700-750 | 1,75 |
| 228,5 - 244,0 | 750-800 | 1,77 |
| 244,0 - 256,0 | 800-850 | 1,79 |
| 256,0 | 850 | 1,80 |

The application of some codes in the design and checks towards the hydrocarbon sector in components of metallic structures as follows:

- APIOCT84 (API 15th Edition Code Check)
- 87APIH (API 17th Edition Hydrostatic Checks)

Fig. 4. Model of Analysis.



- APIH (API 8th Edition Hydrostatic Checks)
- 84NS3472 (1984, Norwegean Standard NS3472 E)
- APIWSD20 (API 20th Edition Code Check)
- 00BS5950 (2000, British Standard BS 5950-1)
- 19902-07 (2007-12-01, ISO 19902 E, Petroleum and Natural Gas Industries Fixed Steel Offshore Structures First Edition)
- AISC13 (American Institute of Steel Construction AISC Thirteenth Edition)
- APIWSD21 (American Petroleum Institute,Working Stress Design, 21th Edition, December 2000)
- ASCE4805 (American Society of Civil Engineers, 2005 Edition)
- ASD9-E (based on AISC, 1989)
- EC3-2005 (Eurocode 3: Design of Steel Structures)
- IS800 (Indian Standard IS:800-1984)
- LFRD3 (AISC Load and Resistance Factor Design Third Edition)
- N690-94 (ANSI/AISC N690 1994 Edition)
- NF-2004 and NF-2007 (ASME-Section III, Division 1 - Subsection NF 2004 and 2007 Editions).

## Methodology

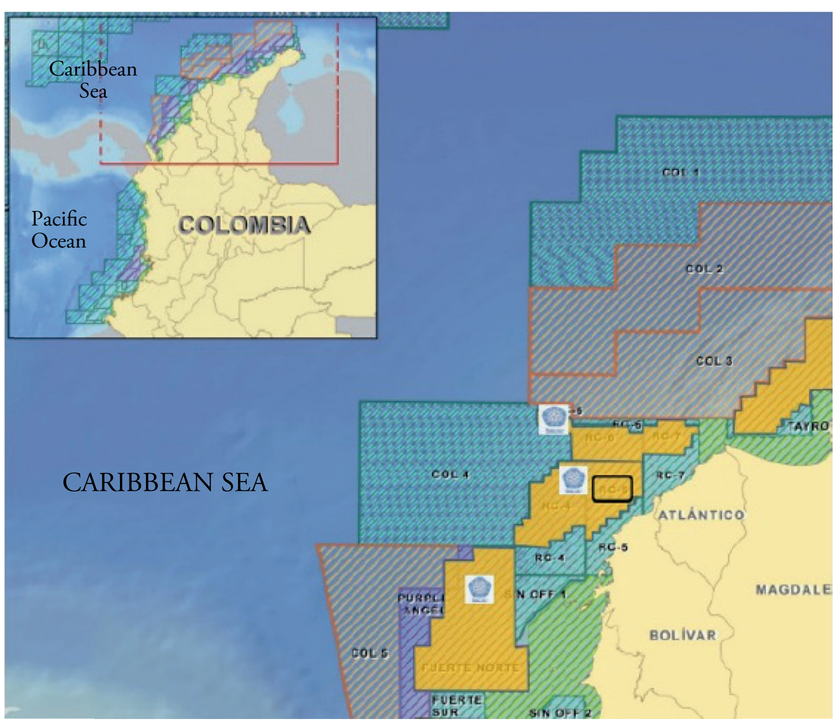
Fig. 5 details the model of analysis for the structural design of platforms type Jacket applied to the Colombian Caribbean sea. Considering its location for operation, it is determined that the environmental characteristics corresponding to the adequate depth ranges for these types of structures.

The dimensions and geometry, and structural arrangement of the unit, will likewise depend on the environmental conditions, seismic conditions of the seabed as well as on the capacities destined to exploration and/or production of the field, distance to land or exploration system selected.

In the evaluation of the hydrostatic and hydrodynamic loads it is necessary to select the adequate wave theory having previously studied the aspects related to the cinematics of particles.

They are likewise included as one of the most important stages of the process of application of design and check codes.

Fig. 5. Location Block RC5 Pozo Mapale1 en Galerazamba, Colombian Caribbean [4].



# Results

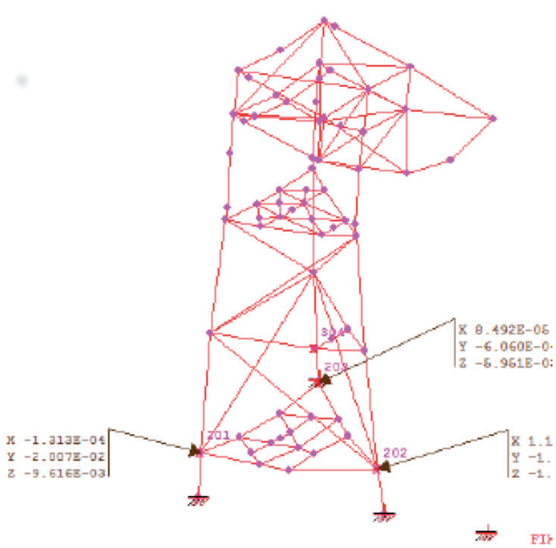
As application of the proposed methodology, a study case of structural design was carried out on a new platform to be located in block RC-5 of the Colombian Caribbean sea, Fig. 5. A structural arrangement type 3 is selected, Fig. 1, in accordance with the characteristics and environmental conditions, particularly low depth and minimum seismic activity in the region, wave characteristics represented in Table 3.

In the calculation of the environmental loads and the analysis and check of the structural components, we relied on the GTSTRULD Y GTSELOS System [7], obtaining the permitted deformation results, Figure 6 and resistance, which were verified through standard API 2A-WSD. As shown in Fig. 7, no member exceeds the limit percentage of the load.

To evaluate the behavior of the platform a stiffness analysis is performed considering the interaction of the loads with the structure, considering also the effects originated by the hydrostatic pressure (Hydrostatic Collapse).

To verify the structural resistance of the elements, a review of the acting efforts is made in the structural elements according to the design standards and criteria, which for our case is APIWSD21, given that it is current in the database of the System used GTStrudl [7].

Fig. 6. Maximum movement in nodes [7].

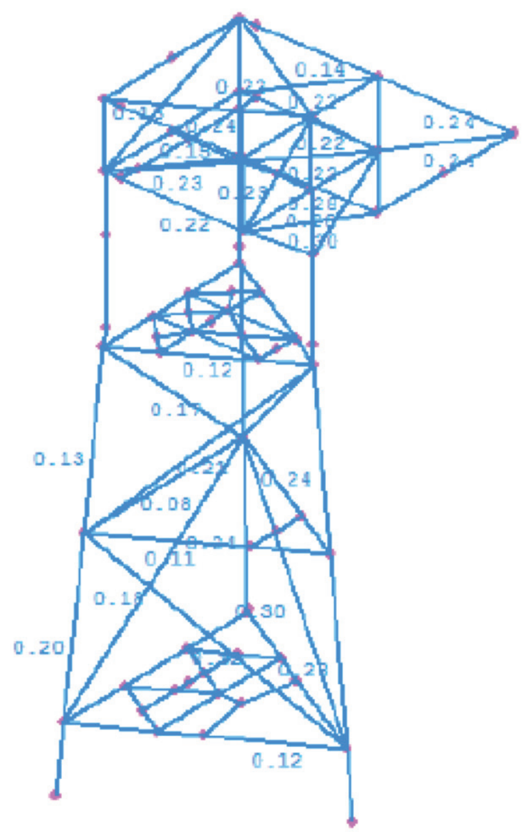



| Nodo | Desplazamiento X (inch) | Desplazamiento Y (inch) | Desplazamiento Z (inch) |
|---|---|---|---|
| 201 | -0,0001313 | -0,02007 | -0,009616 |
| 202 | 0,01123 | -0,01792 | -0,0161 |
| 203 | 0,0000849 | -0,000606 | -0,005951 |

Table 3. Characteristics of the status of the wave in the Region of Analysis [1].

| Definition | Value |
|---|---|
| Depth (d) | 150 mts |
| Height of wave (H) | 1.6 mts |
| Peak Period (Tp) | 19 sec |
| Drag coefficient (Cd) | 1.0 |
| Inertia Coefficient (Cm) | 2.0 |

Fig. 7. Code Check of the structure [7].



## Conclusions

As there is a need for new discoveries, increase the reserves and the production in the Colombian Caribbean sea at depths up to 300 meters, an increasing development of the infrastructure in offshore platforms type jacket is expected. This research paper proposes a methodology of analysis and structural design considering the theoretical foundations and field information necessary to provide reliable systems type Jacket according to its functionality and the region of location. Information such as the environmental characteristics and the depth of the operating site, become necessary data to select the adequate theoretical foundation for the development of the analysis.

The model of analysis was applied for the design and analysis of a platform type Jacket according to the environmental conditions of Block RC-5 of the Colombian Caribbean sea, complying with the parameters permitted by the design standards for these types of structures. The presented methodology will make make the development of future works easier within the field of study of offshore engineering in the Colombian Caribbean region.

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System of Finite Elements and Environmental. Loads GTSTRUDL-GTSELOS.

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