Logistics Simulation of Offshore Production Sites

Doğukan Melih Görmüş

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Supervisor: Dr. Ludmila Filina-Dawidowicz, "ZUT" West Pomeranian University of Technology, Szczecin, Poland

Prof. PhD. Jean-David Caprace, "UFRJ" Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

Reviewer: Prof. Ing. Dario Boote, "UNIGE" University of Genoa, Genoa, Italy

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LIST OF ABBREVIATIONS

AIS	Automatic Identification System
BCL	Batch Control Language
DES	Discrete-Event Simulation
FPSO	Floating Production, Storage and Offloading
GPS	Global Positioning System
GUI	Graphical User Interface
IMO	International Maritime Organization
O&G	Oil and Gas
$Platform_x$	X coorditane (longitude) of the offshore production site
$Platform_y$	Y coorditane (latitude) of the offshore production site
PSV	Platform Supply Vessel
R	Radius of the specified zones
SCL	Simulation Control Language
$Ship_x$	X coorditane (longitude) of the ship in each A.I.S. signal
$Ship_y$	Y coorditane (latitude) of the ship in each A.I.S. signal
SOLAS	Safety of Life at Sea
SS	Semi Submersible

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I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Where I have consulted the published work of others, this is always clearly attributed.

Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

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ABSTRACT

Logistics of offshore production sites is rising in importance due to massive increase in exploration and production of oil and gas. In addition to this, the number of production sites and number of the ships that are working in these fields such as crude oil tankers and Platform Supply Vessels (PSV) are increasing significantly with the complexity of logistics operation process.

Although there are some researches about fleet efficiency of supply vessel in offshore logistics, there are only few studies simulating the complete supply chain management of the offshore production fields. This thesis covers the investigation of the logistics of supplies and transportation of oil from/to offshore production sites around Brazilian coasts. Besides, it proposes an option to extract relevant information from an AIS (Automatic Identification System) database and use this information to create the inputs of a stochastic simulation about logistics of offshore production sites.

A database which contains 6 months of AIS tracking data for 90 ships has been analyzed. An algorithm has been developed to be able to identify the behavior and role of each PSV and each crude oil tanker in the studied offshore supply chain.

Offshore logistics activities in Campos Basin, i.e one of important coastal sedimentary basins of Brazil, has been modeled by using Discrete Event Simulation (DES) methodology. It includes 5 ports, 15 crude oil tankers, 23 PSVs and 38 offshore production platforms such as FPSO (Floating Production, Storage and Offloading), fixed platforms and SS (Semi-submersibles). Several distributions have been extracted for each type of ship and operation profilethen used as input variables for the simulation. Following the implementation of stochastic parameters into the model, the simulation is repeated until it reaches to convergence.

The preliminary results show a good accordance between simulation outputs and measured data from AIS database. However, future work is required to improve the offshore supply chain simulation and robustness of the simulation. Optimization is also a possible improvement for the next future. We suggest that DES is a useful tool to make precise analyses and decisions in offshore logistics applications.

1. INTRODUCTION

1.1. Context

Offshore oil and gas industry is one of the most important industries in the world with a direct impact on the worldwide economies. It has become a remarkable source of energy over the past years due to swift increase in global energy needs. According to annual world energy statistics, it is stated that in 2012 approximately 57 percent of total energy consumed in the world has been produced from oil and natural gas [1].

On the other hand, renewable energy is requesting from the society, but it is not possible to supply the global energy demand purely based on renewable energy today or in the relative near future. Thus, Oil and Gas (O&G) will continue to play the major role in the world's energy production in order to meet this increasing demand. Some studies predict that the usage of oil will be doubled in 2025 [2].

Over the last decades, the oil and gas industry has expanded consistently from land operations to inland waterways and then to the offshore to serve this purpose [3]. New type of vessels and drilling technologies have been developing with this intention to be able to reach deeper waters and further points for offshore exploration and production activities.

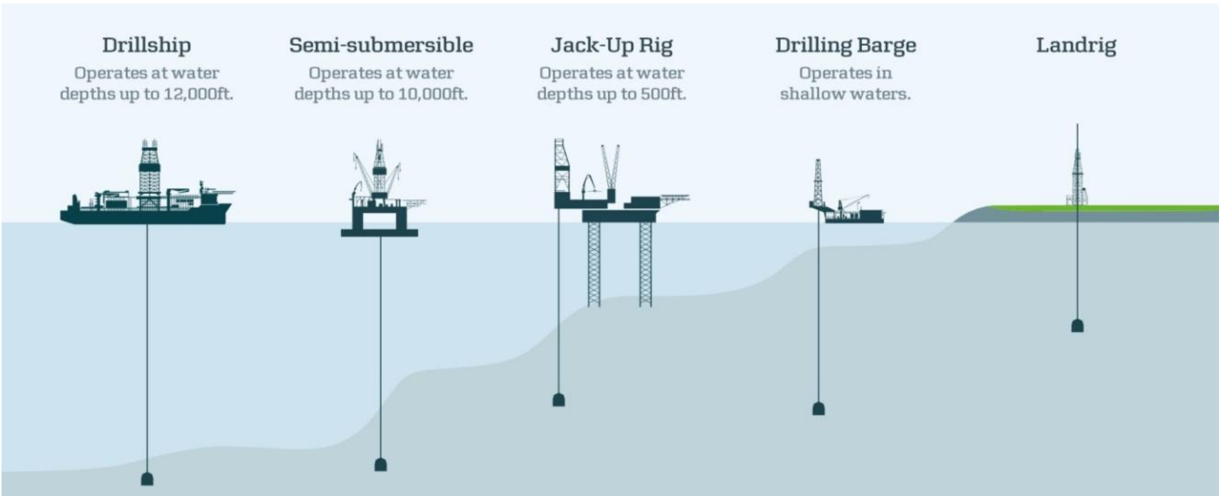

Figure 1. Different types of production facilities, based on depth of water [4].

Also driven by rising oil prices and fleet replacements, total offshore vessel deliveries have been tripled between 2004 and 2009 [5]. But after the sharp decrease of oil prices in the second half of 2014, oil companies announced reductions of their oil exploration investments.

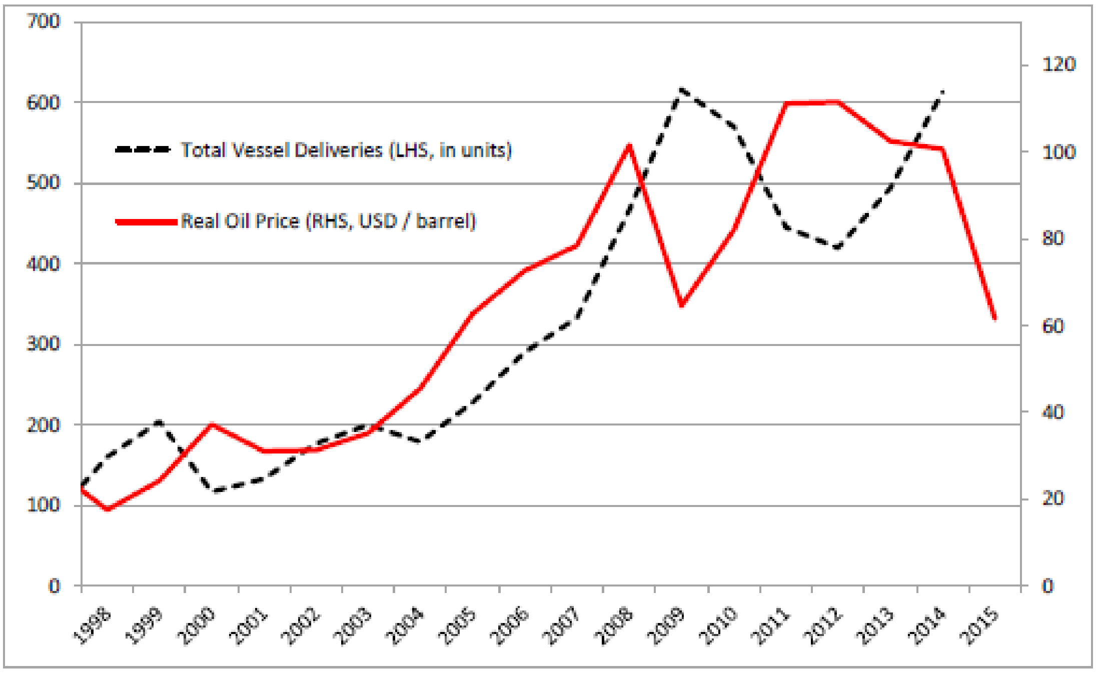

Figure 2. Offshore vessel deliveries (in units) and oil price (in USD per barrel)[5].

Offshore vessel deliveries are expected to decrease around 10% in 2015, and further decreases are expected in 2016 and 2017. Nevertheless, over the medium-term, demand of all offshore vessel types is expected to increase by 3.7% per year on average over the next ten years due to developments of deep offshore fields [5].

It means the number of production sites and number of the ships that are working in O&G fields such as crude oil tankers and offshore supply vessels will continue to increase significantly with the complexity of logistics operation process.

As a result of this massive growth, efficient way of supply logistics becomes the major challenge for the offshore production sites. That’s why simulating the complete supply chain management of the offshore production fields can be very beneficial in terms of efficiency and optimization for offshore logistics activities.

1.2. Background

This master thesis has been prepared within the framework of EMSHIP which is Advanced Masters Program that gives Double Degree in Naval Architecture and Applied Sciences of Mechanics. The research has been accomplished as researcher at Federal University of Rio de Janeiro (UFRJ) in the Simulation Laboratory of Ship Building Processes (LABSEN) under the supervision of Professor Jean-David Caprace, in Brazil. The thesis has been written during the last semester of EMSHIP program under the administration of West Pomeranian University of Technology (ZUT) in Szczecin, Poland with the supervision of Professor LudmilaFilina-Dawidowicz.

1.3. Gap

As can be seen on Figure 3, logistics of O&G production is divided into two parts: downstream and upstream logistics. Downstream logistics is defined as bringing O&G to onshore. Upstream logistics is supplying the offshore drilling and production units with necessary supplies.

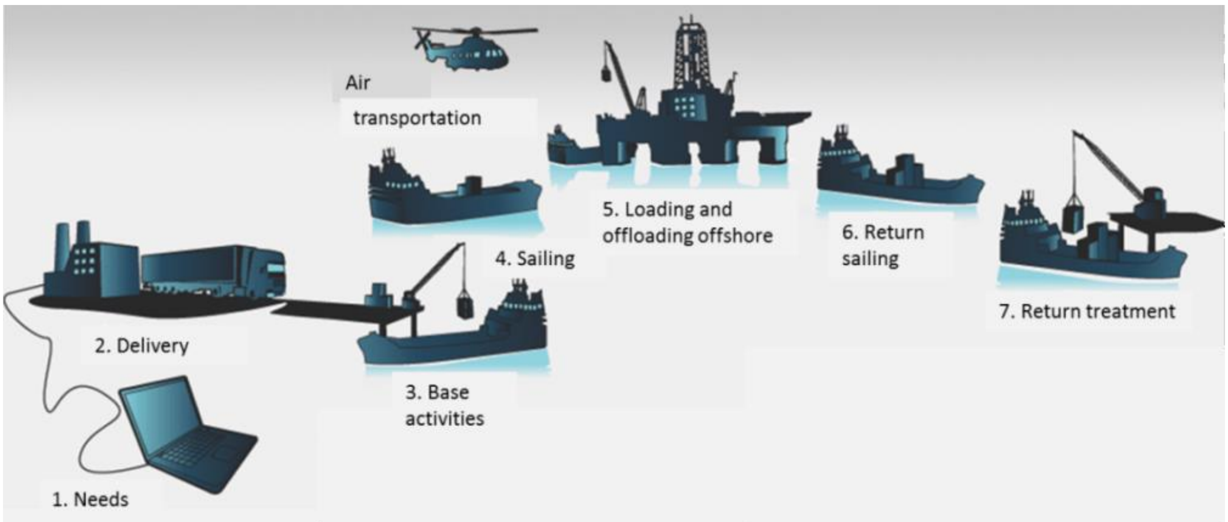

Figure 3. Downstream and upstream parts of offshore logistics [6].

These topics have been studying separately or together since 2000's. In scientific literature, there are some researches about offshore logistics with different approaches, objectives, methods and proposals such as efficiency of supply vessel fleet, role of supply vessels in offshore logistics, planning of supply vessel's operations. However, there are only few studies about simulating together the entire downstream and upstream logistics of offshore production sites by using Discrete-Event Simulation (DES).

This master thesis covers the investigation of the logistics of supplies and transportation of oil for offshore production sites around Brazilan coasts. One of the main differences of this study from the earlier studies is that it proposes an option to extract relevant information from an AIS (Automatic Identification System) database and use this information to create the inputs of a stochastic simulation about logistics of offshore production sites. Furthermore it can be used to make precise analyses and decisions in all kind of offshore logistics applications. In different sections of the thesis detailed information will be explained.

1.4. Objectives

The main focus area of this thesis is to create a simulation of logistics for offshore production sites which aims to enable work on the complete supply chain management of offshore logistics fields by using DES (Discrete-Event Simulation).

As the structure of the study, a database has been analyzed. It contains 6 months of AIS tracking data for the 90 ships that has been working in Brazilian coasts between April 2014 and October 2014. In addition to that, an algorithm has been developed to be able to identify the behavior of each PSV and each crude oil tanker in the offshore supply chain.

In this thesis, offshore logistics activities in Campos Basin, i.e one of the most important coastal sedimentary basins of Brazil, have been modeled and it includes 5 ports, 15 crude oil tankers, 23 PSVs and 38 offshore production sites such as FPSO (Floating Production, Storage and Offloading), fixed platforms and SS (Semi-submersible).

Several distributions have been taken for each type of ship and each type of operation and these distributions have been used as the variables of the simulation. Following the stochastic parameters included into model, the simulation is repeated until it reaches to convergence. As it is expected the preliminary results show a good accordance between simulation outputs and measured data from AIS database.

Yet another aim of this research is to generate an interest of using DES for offshore logistics operations and supply chain management decisions. So that with an additional future work, the created simulation model can be adopted as a tool to examine the efficiency of existing support vessel fleets, to identify the effect of different logistics operational strategies for offshore logistics activities, i.e. deciding routes of vessels, defining the number of supply vessel per offshore platform, deciding the fleet size.

1.5. Structure of the Thesis

The introductorion chapter of this thesis mainly contains the information concerning the background of O&G industry and current problems regarding logistics of offshore production sites, the scientific gap regarding why such kind of study has been performed and objectives with respect to the aims of the comprehensive work has shown.

In chapter 2, the current literature related to efficiency and importance of offshore suply vessels and simulations of offshore logistics activities has been discussed briefly. The approach into the A.I.S. database analysis and the reasons for choosing Discrete-Event Simulation methodology has been justified.

The main steps regarding the development of algoritm to analyse the A.I.S. database has been provided in chapter 3. The crucial database analyses made concerning the behavior and role of vessels and offshore logistics operations has been explained. Focus has been placed on the "Extracting Relevant Distributions" that have been used in the simulation model as stochastic variables.

In chapter 4 the structure of the research and the created simulation model has been presented. Brief information has been given about the simulation elements and the creation processes of the model, including the description of the simulation system, followed logics, data implementations, assumptions and simplifications.

Chapter 5 contains the results of the studied simulation case. Simulation result has been compared with the real measured data.

Chapter 6 is dedicated to demonstrate the conclusions derived from the obtained results. Additionally, possible improvement suggestions for the near future and future work opportunities took place in this chapter.

In chapter 7, acknowledgements and giving thanks to people who made a contribution to this thesis.

Lastly, in Chapter 8 analysed literature, journal articles, books, thesis and internet-based sources has been stated as references.

2. STATE OF THE ART

Offshore production sites are crucial in one of the biggest industries in the world and has significant role in world economics. Therefore, logistics of these production sites are gaining importance rapidly in recent years. There are some works in the field of efficiency of offshore supply vessel fleets in offshore logistics and some studies related with the simulation of complete supply chain management of offshore production fields.However, it can be said that there is relatively limited number of publications and researches in that field.

Aneichyk [7] relates the importance of offshore supply vessels in offshore logistics by stating that they are costly resources. It is also stated that petroleum industry has key importance in economic growth and stability in Norway where the study is done. Therefore, it is fair to say that oil industry is crucial and this fact raises the importance of offshore logistics as well. The work covers the designing of a simulation model for offshore supply process with the aim of creating a tool to plan the operations and fleet size. Some uncertainty factors affecting the process are taken into account such as weather conditions, varying demand and delays occurring in supply. A Discrete-Event Simulation model is developed within the task in order to model those uncertainties with a stochastic approach. ARENA software was used for creating the simulation. Results obtained show that simulation may be seen as an important tool to develop new strategies under varying conditions and improve the efficiency of the process dramatically. Therefore it can be stated that the article supports the fact that simulation has a promising future in offshore logistics field and the usage will increase in near future.

Skoko et al. [8] underlines the fact that offshore logistics is a complex problem that is dependent on several stochastic variables. Continuity of supplement required service and items are crucial. The author also offers an insight understanding of the current industry and how companies work. It is stated that most companies charter almost every unit such as drillers or offshore supply vessels which has direct effect on cost. Within the work, the fact that daily offshore supply vessel rates and crude oil price are linked is proved and supported. The role and current condition of offshore vessels are investigated and it shows that these vessels cover great importance part in the industry. West Africa market is investigated in the paper to support the ideas. It is fair to state that the article shows the economical aspect of logistics of offshore vessels and importance of fleet management according to oil price which is fluctuating dramatically.

Thesis of Nordbo [9] is an important paper dealing with offshore logistics subject which has the objective of comparing different alternatives for improvement of remote locations offshore supply service. Two alternatives that are discussed within the thesis are a conventional system, in which PSVs sail directly between storage unit on land to offshore platforms, and an alternative solution, in which two converted ships are used as storage units located near offshore field. An optimization software, Express, is also used to create and solve mathematical formulations and assess the alternatives. The results show that having storage units may increase the profits in some cases.

Friedberg and Vidar [10] present a case study in Petrobras. The objective is to figure out a method to improve decision making process regarding the routing and scheduling of PSVs. Similar to content of our work, the study is conducted in Campos Basin. It is stated that predicted growth of the company and current demand level raises the necessity to improve in every field of organization of Petrobras including logistic as well. Therefore a planning tool is required to improve efficiency of handling orders. Based on the article, it can be said that proper logistics planning is a key concept in increasing profitability of the offshore processes.

The thesis presented by Ashish [11] is on the subject of logistics of offshore wind turbines. Despite the fact that it may be seen irrelevant with logistics of offshore sites, the basic idea is parallel with our task. Besides that the author is dealing with wind turbine, the goal is to develop the logistics and maintenance strategies and reduce the costs eventually. A stochastic time based logistic model is developed within the framework of the thesis. Then it is analyzed with the objective of identifying and selecting the most cost-effective strategy. The developed model enables the author to identify several parameters such as inventory stocks, downtime other service and logistics related data, finally leading to the costs as well.

Azad [12] briefly underlines the importance of offshore industry and role of PSVs in the industry. The author states that performance of these vessels is also important and their performances are needed to be monitored. The thesis is a good source to see the future of the offshore oil and gas industry as well, as it can be seen that industry is expanding to the unexplored regions like Arctic region which offers several uncertainties such as sensitive environment, tough weather, distant area and lack of infrastructure. All these difficulties directly affect vessel performances and logistics planning. Therefore it is fair to state that in near future, PSVs are needed to fulfil harder missions and it is crucial to plan and develop logistics of offshore sites in order to overcome uncertainties and challenges.

Literature search showed that there are some academic studies and applications related with logistics of offshore production sites.The articles and thesis studies shown above were taken as a starting point to understand the nature of offshore logistics and importance of this concept. However it can be said that compared to the importance and size of the industry, the number of these works is relatively small and it is expected to increase in the near future.

The study that has been done in this thesis covers the investigation of the logistics of supplies and transportation of oil from/to offshore production sites around Brazilian coasts yet it proposes an innovative and different approach comparing to others.Such as extracting relevant information from an AIS (Automatic Identification System) database and use these information to create a stochastic simulation about logistics of offshore production sites by using Discrete-Event Simulation methodology.

3. DATABASE ANALYSIS AND IMPLEMENTATION

3.1. Chosen Basin Characteristics

Understanding the dynamics of oil exploration and production fields has a great importance to perform an offshore logistics simulation. In order to do that, some general characteristics of the surveyed basin are given in this section.

Campos Basin is one of 12 coastal sedimentary basins, as main producing oil province of Brazil. It spans both on-shore and off-shore parts and is located coast of Rio de Janeiro with an area of approximately 100,000 square kilometers.

It has a long exploration history in offshore Brazil that dates back to 1974. Besides in the last 30 years, several giant fields in Campos Basin, (e.g. Albacora, Marlin, Roncador, etc) were discovered in deep and ultra-deep waters. As an example of this, Papa Terra field is a heavy crude oil field which was discovered in 2003 and started production in 2005 .The field lies at a water depth of 1190 meters and 110 kilometers distance from the shore of Brazil [13].

Figure 4. Campos basin location [14].

More than % 91 of Brazil's oil production is offshore in very deep water with well established oil infrastructure. The basins of Rio de Janeiro produced 1.54 million b/d in 2014, accounting for % 68.4 of the total production [15]. Thereby, very complex and excessive logistics activities are taking place every day in Campos Basin to respond this massive production demand.

In addition to all these, due to the discovery of Pre-Salt layer in Brazilian continental shelf in 2006, the importance of Campos Basin has been increased one more time. Because the current findings in the region of the Pre-Salt, can mean reserves of over 50 billion barrels of oil. This amount is four times greater than the current national reserves of Brazil (roughly 14 billion barrels) even though drilling through the rock and salt to extract the O&G is very expensive. As an example to this, the well known semi-public Brazilian multinational energy corporation Petrobras, is expecting to reach total production of O&G (Brazil and International) of 3.7 million boed in 2020 and expects that by then, Pre-Salt will represent more than %50 of total oil production. [16]. Hence this expansion requires an increase in capacity on all levels of the organization including logistics too.

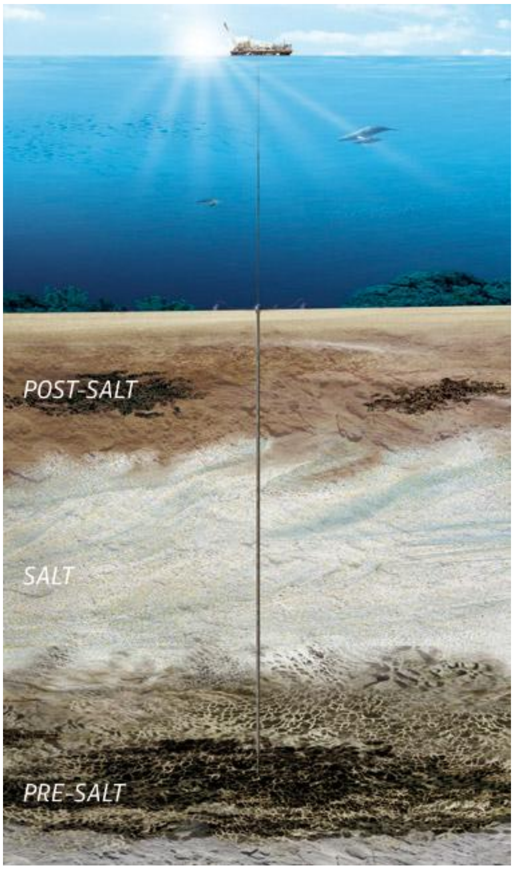

Figure 5. Representation of Pre-Salt layer [17].

In Pre-Salt region there are large O&G reserves located under salt layers that extend for 800 kilometers along the Brazilian coast and up to 300 kilometers offshore. The oil and natural gas lies below an approximately 2000 meters deep layer of salt, itself below an approximately 1000 - 3000 meters deep layer of rock under 2000 meters of the Atlantic Ocean. It means that there is a depth varying from 5000 meters to 7000 meters to be drilledin order to reach the huge amount of reserves.

That is why the Pre-Salt region in the Campos Basin is more attractive to oil companies because the salt layer is not as thick as in the Santos Basin [15]. Therefore all these developments, with the rising distances to offshore and going ultra deep waters, poses logistical challenges for offshore production sites in terms of supply of bulk materials, transport of people (helicopters or boats), pipeline laying vessels, drilling rigs and terminals for oil export through commercial crude carriers [18].

3.2. A.I.S. Database Analysis

The A.I.S. (Automatic Identification System) is an automatic tracking system which is using to identify and locate the ships by electronically with G.P.S. (Global Positioning System)and exchange data with nearby ships, other A.I.S. base stations and satellites.

Furthermore according to the 2002 IMO SOLAS agreement, it is mandatory that vessels over 300GT (Gross Tonnage) are equipped with A.I.S. transceiver [19]. It is a major development to improvesafety of life at sea, the safety and efficiency of navigation and the monitoring of passing traffic by coastal states.In order to do that, A.I.S is always in operation when ships are underway or at anchor and the provided data is public.

During this research, a database has been studied from several perspectives. The database contains the A.I.S. information of 90 ships that has been working for logistics activities of offshore production sites around Brazilian coasts from 1 April 2014 to 1 October 2014.

The database includes following information:

- Ship type,
- Ship speed (knots),

- Ship course (degrees),
- Ship position (Latitude & Longitude),
- Date & Time.

In addition to this, another database has been analyzed, which contains data about 190 offshore production sites, with the following information:

- Name of each offshore production site,
- Type of each offshore production site such as FPSO, fixed platform and semi submersible,
- Current location of each offshore production site (Latitude & Longitude),
- Status of each offshore production site (still in operation or decommissioned).

3.3. Developed Algorithm

3.3.1. Main steps of developed algorithm

An algorithm has been developed to extract requisite information from database to be able to identify the behavior and role of each crude oil tanker and each PSV in this offshore supply chain. In order to do that, every ship has been analyzed separately by using the existing information in the A.I.S. database and by combining this information with the database of offshore production sites. Basic steps of the algorithm are shown on Figure 6 and each step has been described as subsection.

Excel macro software has been chosen for creating the one-button-triggered database solver. Because it is easy to use in many aspects such as scripting, automate the tasks and build the logic of algorithm. Therefore, codes of the solver have been written in visual basic programming language and the only needed input for the analysis is the raw A.I.S. transceiver data from the vessels.

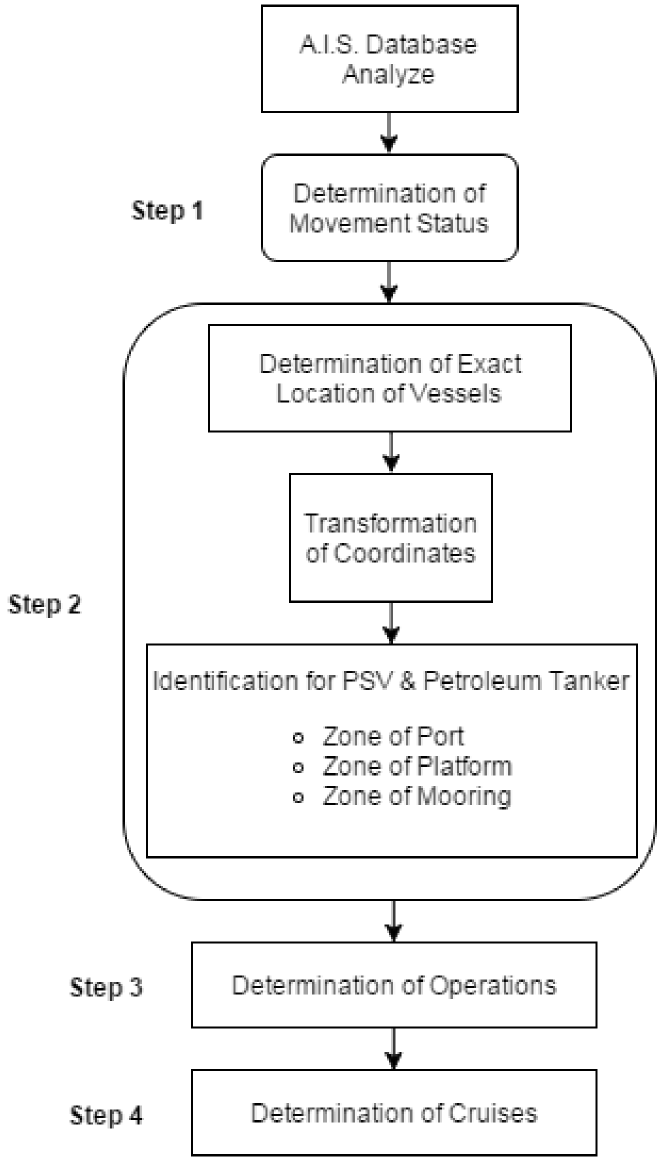

Figure 6. Main steps of developed algorithm.

Besides that, another software has been used which is called as KNIME. It allows visually creating data flows for data mining, data transformation and inspecting the analyze results with interactive views. After each analyze that has been done for each PSV and each crude oil tanker, all outputs of solver have been checked to obtain proper results by using the map integration tool of KNIME.

An example to the usage of map integration tool of KNIME can be seen on Figure 7. It shows the difference between raw image and processed image of A.I.S data for the same PSV.

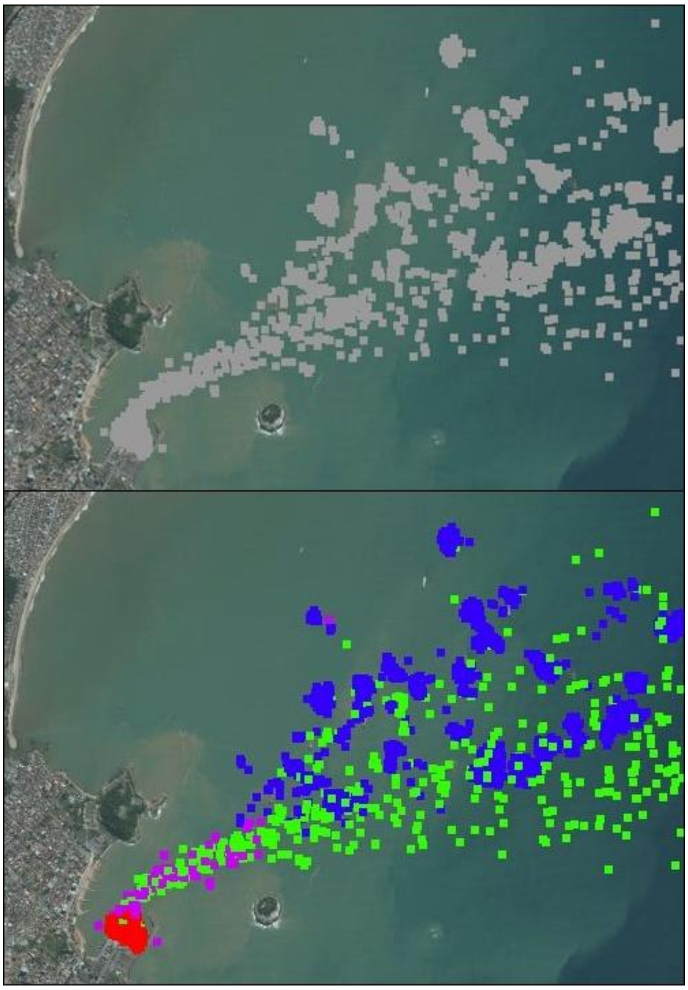

Figure 7. Comparison cover of raw data (up) and processed data (down) for a PSV.

On the basis of A.I.S. database analysis, recorded positions (points) have been divided into 7 groups. Table 1 show these prevalent identifiers to define the signal colors on Figure 7 and for all the other relevant map figures.

Table 1. Legend of record points.

Color of Record point	Description
Red	Loading – Unloading
Purple	Waiting
Green	Sailing
Blue	Mooring
Black	Offshore Production Site
Gray	Raw Appearance
Yellow	Cruise

3.3.2. Determination of movement status

Initial step of algorithm development was to calculate the average velocity between two successive record points. These points are the navigation points which have been sent by A.I.S. trancevier in each signal. In order to make a cross check with the velocity values from database's itself, average velocity (knots) has been calculated by using the difference in time and location between two signals.

$$av.velocity = \frac{\mathrm{acos}\left(\sin(\mathrm{lat}_1)*\sin(\mathrm{lat}_2)+\cos(\mathrm{lat}_1)*\cos(\mathrm{lat}_2)*\cos(\mathrm{lon}_2-\mathrm{lon}_1)\right)*6371000}{\mathrm{t}_2-\mathrm{t}_1} \qquad (1)$$

As a result of cross check, it was decided to continue with calculated velocity for the further steps of algorithm. After that, the movement status of ship has been determined according to velocity of her on that moment, which is shown on Figure 8.

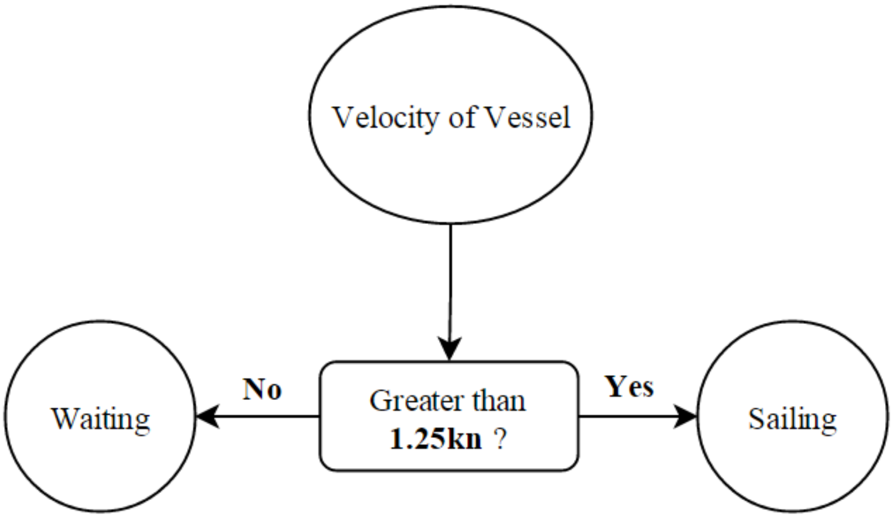

Figure 8. Basic flowchart for movement status determination.

Velocity of 1.25 knots has been set as the limit of movement status determination. Because the velocity data of several ships in the database have been examined to decide the limit of velocity for status separation and 1.25 knots has been found as optimal value. Actually, under "Waiting" status the ship still can continue moving if the velocity is not equal to 0 but this kind of approach has been made to provide convenience for the future stages of problem.

Figure 9 provides information regarding to the movement status of one PSV for each A.I.S. signal and it can be seen from the record points that the ship has decreased her velocity and passed to "Waiting" status and then passed "Sailing" status by accelerating again. Possibly, this kind of status change has occured due to the maneuver of vessel.

However there are some other record points have been observed during theanalysis that the movement status have been changed from "Sailing" to "Waiting" but the vessel have not maneuvered and continued to cruise with really small velocity. Probably, this kind of behavior can be explained as ships are just drifting and not using their own propulsion system during that time period.

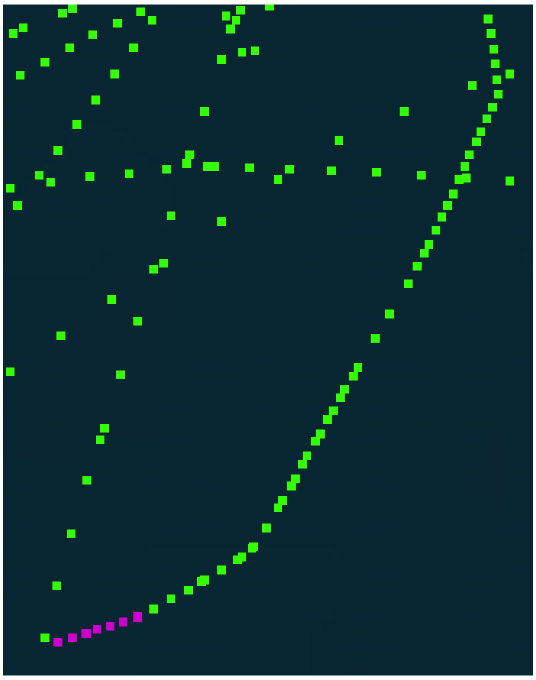

Figure 9. Purple points mean "Waiting" status and green points mean "Sailing" status.

3.3.3. Determination of exact location of vessels

In the second step of algorithm, the purpose was to determine where the ship is exactly such as if she is at port or mooring or approaching to the platform. In order to do that, a basic circle equation has been used. But since it is not possible to write a circle equation by using latitude and longitude values, these values have been transformed to x – y Cartesian Coordinates in units of meters by using Mercator projection method which is the basis of UTM (Universal Transverse Mercator) system, which can be seen on Figure 10.

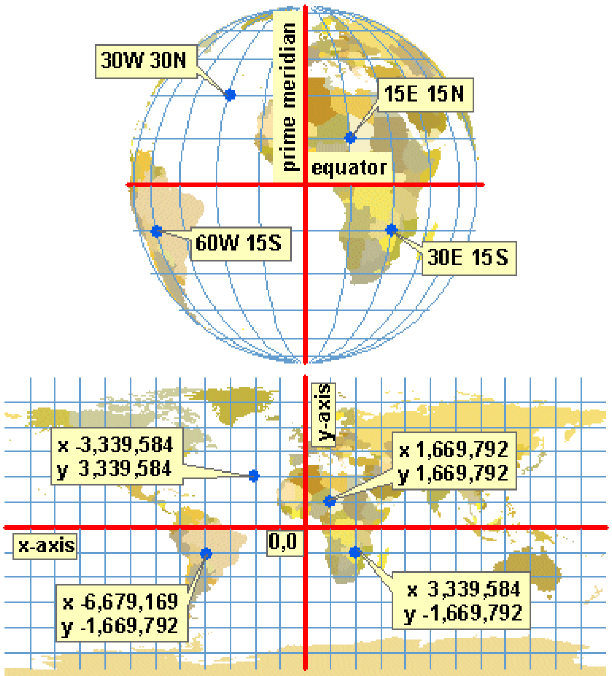

Figure 10. Transform from longitude – latitude to x – y [20].

Mercator projection is a cylindrical map projection on which both the lines of latitude and lines of longitude appear as straight lines running parallel and perpendicular to each other. As on all map projections, shapes or sizes are distortions of the true layout of the Earth's surface, the Mercator projection exaggerates areas far from the equator. But the scale is reasonably accurate for area representation and transformation in equatorial regions [20]. Hence it does not constitute a problem to use this transformation for Campos Basin region.

Transform formula for the longitude decimal is;

$$X = lon * \frac{\pi}{180} * 6371000 \quad (2)$$

Transform formula for the latitude decimal is;

$$Y = ln\left(tan\left(\frac{lat * \frac{\pi}{180}}{2} + \frac{\pi}{4} \right) \right) * 6371000 \quad (3)$$

All the latitude – longitude data of each vessel for each recorded position and location of each offshore production site have been transformed to x – y coordinates by using formulas 2 and 3.

After the transformations completed, the equation, that is determining if the ship is inside the zone of port or zone of offshore production site or not, has been written as below;

$$R < (Ship_X - Platform_X)^2 + (Ship_Y - Platform_Y)^2 \quad (4)$$

The coordinates of every port and every offshore production site is composing the center of their own specified zone. Algorithm calculates the zone, which is determined with a certain diameter, for each port and each offshore production site in the database. Then, for each signal that has been sent from the A.I.S. transceiver, it measures the distance between ship and all ports and offshore production sites. When the measured distance is getting lower than the radius of that zone it means the ship has been started to enter the zone.

Although A.I.S. transceiver sends the location of vessel as latitude – longitude values, it is not possible to know the exact place of the vessel. Such as from which port or which platform the vessel has been sending the A.I.S. signals. So by courtesy of equation 4 it is precisely possible to determine the exact location of the vessel.

Figure 11. Port of Macaé zone with 150 meters radius.

As can be seen on Figure 11 and Figure 12, Port of Macaé has its own specified zone and moreover by observing the movements of vessels in all these specified zones, in every port and every offshore production site, the loading – unloading operations that have been performed by PSVs and crude oil tankers have been determined.

Figure 12. A.I.S. signals from the Port of Macaé zone.

Another contribution of this approach is to determine the mooring areas for PSVs and crude oil tankers. By observing the locations, excluding port and platform zones, where ships have velocity between 0 and 1.25 knots, which means under "Waiting" status, have been defined as mooring zones.

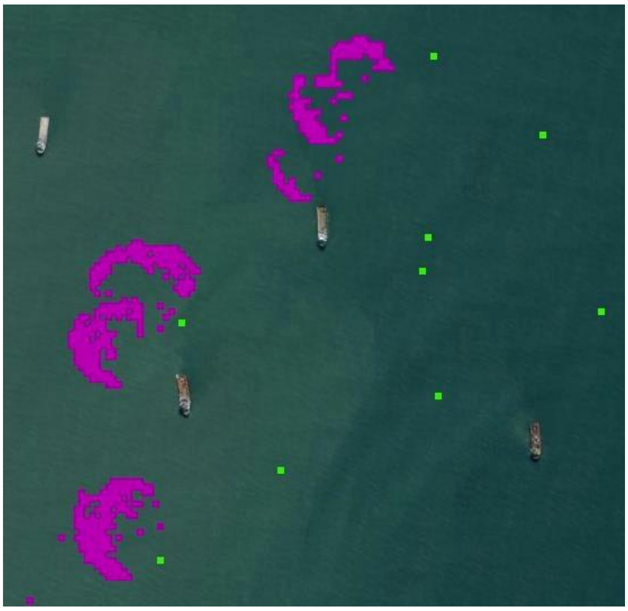

Figure 13. A.I.S. signals from mooring zone at Macaé.

So one of the locations that has been defined as mooring zone can be seen on Figure 13. The areas with the purple record points show that the ship has been waiting several times in this mooring zone. That's why, later on these purple points in mooring zones will be shown as blue points to represent the "Mooring".

3.3.4. Determination of operations

One of the main purposes of developing this algorithm was to determine the loading – unloading operations that have been performed by PSVs and crude oil tankers. By combining the first and second part of the algorithm, the third part of the algorithm has been created and that is how each loading – unloading operation has been determined for each ship in the database.

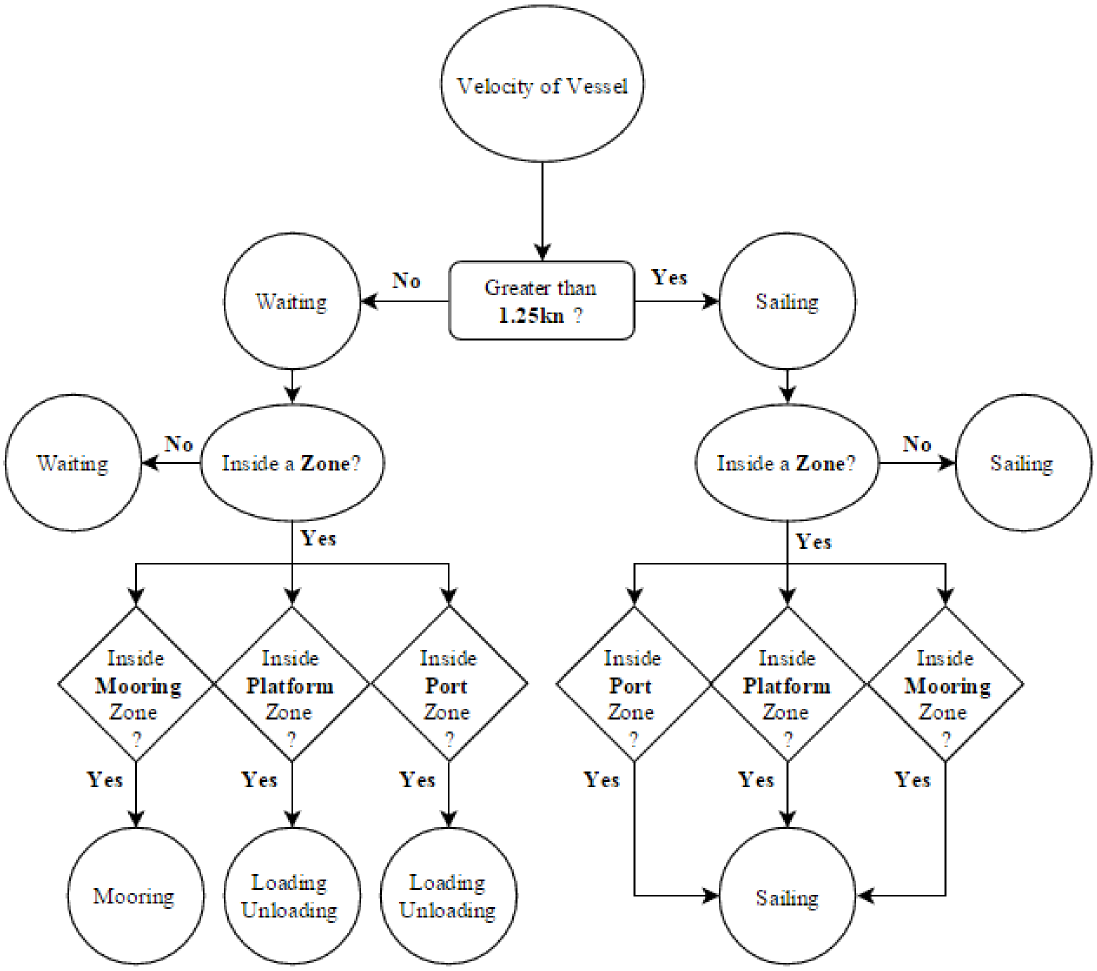

Figure 14. Full flowchart for the operation determination.

Figure 14 provides information regarding to the process logic of operation determination. It is valid for PSVs and crude oil tankers too. Algorithm makes the decision for each record by combining the data about the velocity of vessel and the zone that the vessel is located. Exemplarily to this, if the vessel is under “Waiting” status and at the same time located in “FSO Cidade de Macaé”, the result returns as “Loading – Unloading at Platform” for that signal and from then on the color of the signal starts to return as red.

Furthermore until the velocity of vessel increase and the movement status changes to “Sailing”, the results will proceed to return as “Loading – Unloading at Platform”. Because as it is in real world, it is not possible to perform a loading – unloading operation while the vessel sailing. Hence,in the process logic of this algorithmit is not possible neitherto perform a loading – unloading operation,even if the vessel is located in a port zone or in an offshore production site zone.Therefore,as long as the vessel is under “Sailing” status, it will always stay under “Sailing” in all probabilty, unless the velocity of vessel decrease. So due to the fact that, this kind of record points have not been taken into account as operations. Figure 15 comprises an example for a condition like this.

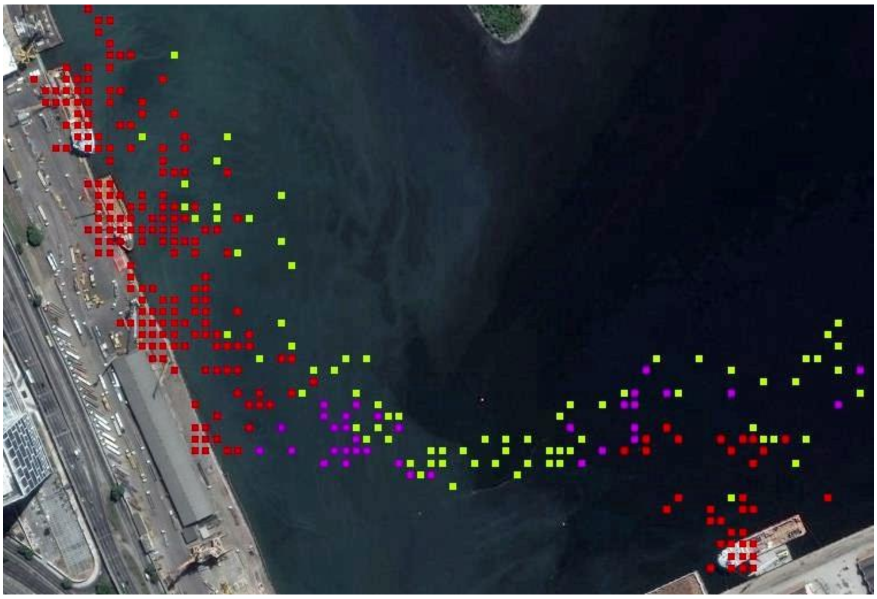

Figure 15. A.I.S signals from Port of Rio de Janeiro.

The different stages of change in the status of the PSV can be seen very well on Figure 15. As an explanation to that, the vessel has been arriving to the terminals of port with “Sailing” status and later on decreased her velocity and passed to “Waiting” status while entering the zone of port. Here it is the color of signals has been changing concordantly with the status of the vessel, from green to purple and from purple to red. Then the loading – unloading operation has been performed and at the end of operation vessel increased her velocity again and left the zone of port. But during all these processes, there are some green record points between the red record points that mean the status of vessel is “Sailing” but inside of port zone. It can be seen on the right bottom corner of Figure 15. So as it mentioned before, these green record points have not been considered into loading – unloading operations.

Figure 16. A.I.S. signals from a crude oil tanker in port of São Sebastião.

As can be seen on Figure 16, a crude oil tanker has been in São Sebastiãocrude oil tanker port zone several times for loading – unloading operations. There are some differences in the procedure of performing the loading – unloading operations between crude oil tankers and PSVs, mainly due to the products that they carried. Because of that the ports and the mooring zones that they have been, differ from the each other. Consequently each port and each mooring zone has been defined separately for the crude oil tankers and the PSVs

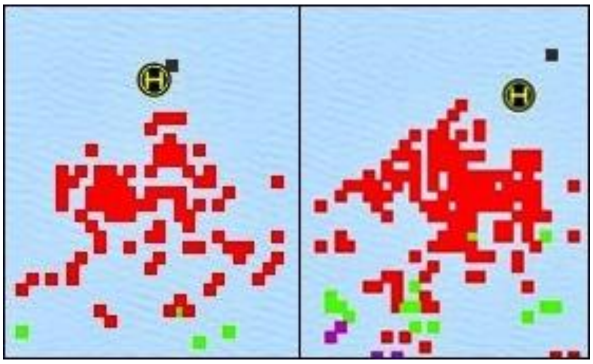

Figure 17. A.I.S signals from offshore production site zones. (H sign means helicopter landing pad)

Figure 17 shows the loading – unloading operations that have been performed by a PSV onto 2 different offshore production sites in Campos Basin. Exactly the same procedure, which has been identified before, has been followed in order to determine the loading – unloading operations on offshore production sites. Moreover the radiuses of offshore production site zones differ from the radiuses of port zones. This is because to have more accurate results in terms of detection of signals for the operations.

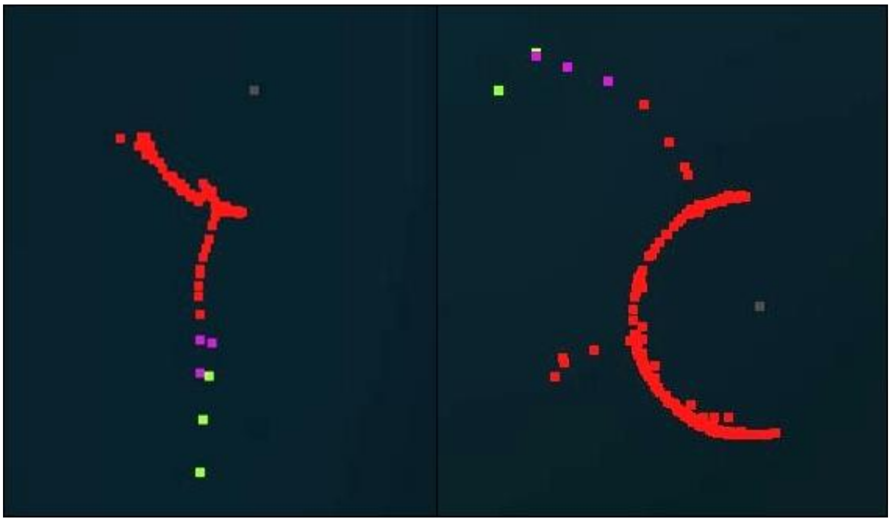

Figure 18. A.I.S signals from a crude oil tanker in offshore production site zones.

Figure 17 shows the loading – unloading operations that have been performed by a crude oil tanker onto 2 different offshore production sites into Campos Basin. Moreover, crude oil tankers and PSVs follow different procedure to perform loading – unloading operations at offshore production sites. Due to this reason,the radiuses ofzones for PSVs differ from crude oil tankers at offshore production sites. This differencecan easily be seen and understood when the signal tracks of PSV and signal tracks of crude oil tanker are compared which can be seen on Figure 16 and on Figure 17.

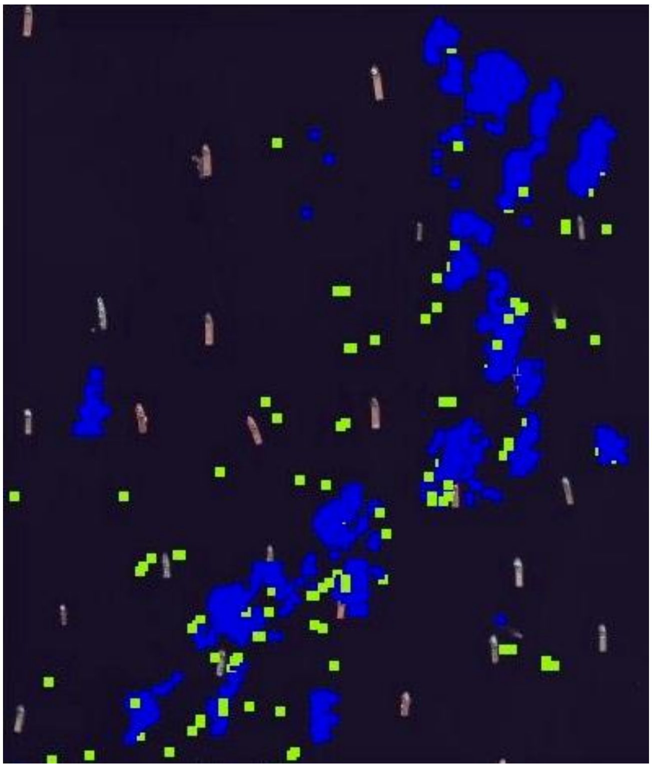

Figure 19. A.I.S. signals from Rio de Janeiro mooring zone.

Another point in the process logic of the algorithm, if the status of vessel is “Waiting” and if the vessel is inside of mooring zone, the new signals will not return as ”Waiting” anymore but will return as “Mooring” and because of this reason the new colors of signal will be blue. That can be seen on Figure 19 for a PSV that has been in mooring zone of Rio de Janeiro several times during 6 months.

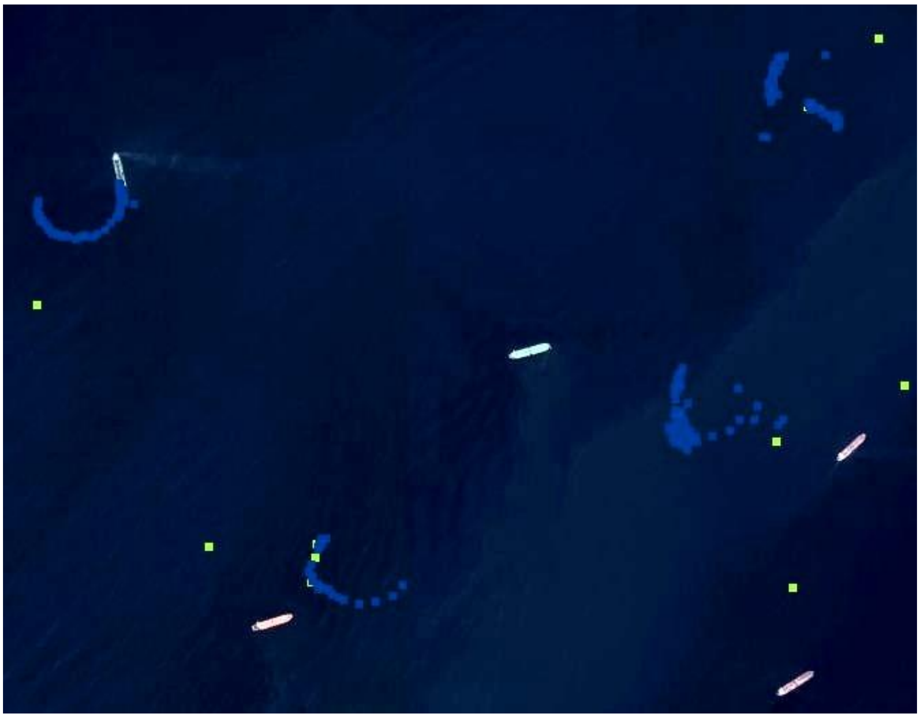

Figure 20. A.I.S. signals from São Sebastião mooring zone.

Figure 20 presents that there are blue A.I.S record points from a crude oil tanker in São Sebastião mooring zone. That means the crude oil tanker with “Waiting” status has entered to that defined mooring zone and because of that the status of crude oil tanker has been changed to “Mooring”.

However, it is also possible that the vessel is in “Waiting” status and not located in one of these specified zones. That’s why in such a case the result of algorithm returns as “Waiting” again. So it means that the vessel is cruising with very low velocity somewhere in Atlantic Ocean but not performing any kind of operation. This kind of behavior of vessels can be explained with the international regulations for prevention of collisions at sea which is effectuated by IMO (International Maritime Organization) due to the high traffic of vessels into that region of Atlantic Ocean or emergencies or reduction in vessel’s velocity for maneuvering.

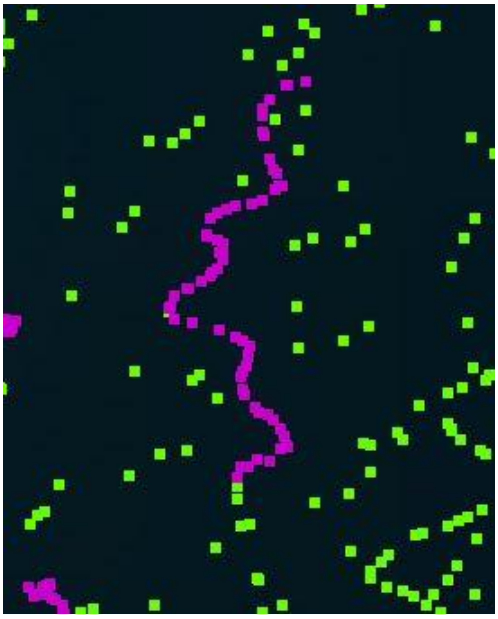

Figure 21. Change in status of a PSV.

The change in the status of PSV from “Sailing” to the “Waiting” can be seen on Figure 21 by observing the change into colors of record points.

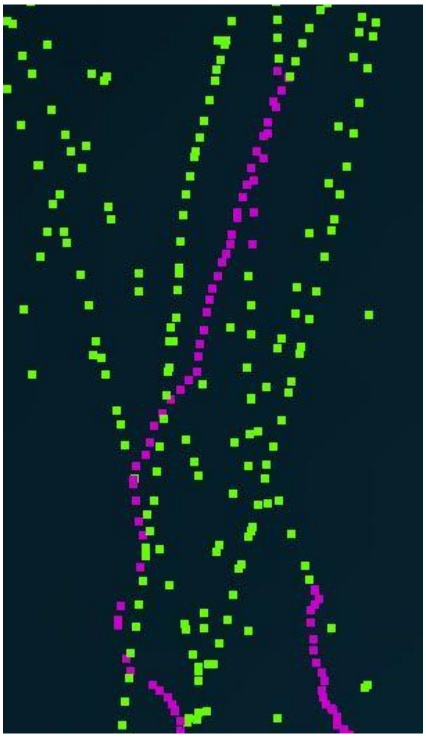

Figure 22. Change in status of a crude oil tanker.

On Figure 22, the change in the status of crude oil tanker from “Sailing” to the “Waiting” can be seen with the change of record point’s color from green to purple.

3.3.5. Determination of cruises

The further benefit of the developed algorithm is the determination of each cruise that the vessel has fulfilled. The underlying logic of this determination process is the usage of the specified port zones. When the vessel leaves one of the ports to go to the offshore production sites to perform the logistics operations, algorithm realizes that the vessel has just been started a new cruise. Just after the logistics operations have been performed and the vessel has arrived back to the port, which can be the same port or another one, algorithm realizes that the vessel came back to the port and it has fulfilled that cruise.

Basically, it can be said that the algorithm uses the process logic that has been using for determining the exact location of the vessels (which has been explained into section 3.3.2) to determine the cruises. In addition to that, algorithm takes into account that if the vessel has performed a logistics operation (loading – unloading operation at platform) after she has left the port. If any logistics operation has not been performed soon after the vessel has left the port, that voyage has not been considered as a cruise since no logistics activity has been performed. Therefore, the cruise has been defined into the algorithm as the voyage that the vessel fulfils with one or more logistics operation between leaving one of the port zones and entering back to the same or another port zone.

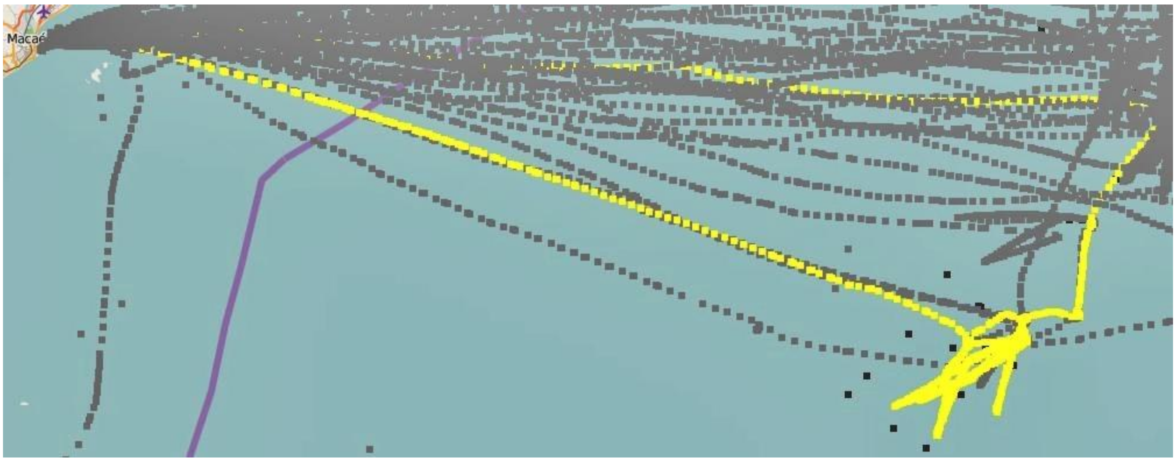

Figure 23. A certain cruise of a PSV among the other cruises.

On Figure 23 one of the certain cruises of a PSV can be seen. The vessel has started to that certain cruise at port of Macaé, touched at some offshore production sites to transport their supplies and then finished the cruise at port of Macaé again.

Also can be seen on Figure 23, this PSV has fulfilled several other cruises into Campos Basin during 6 months to respond the demand of supplies of the offshore production sites. So by using this kind of approach, each cruise that has been fulfilled by eachPSV and crude oil tanker can be determined one by one. Besides that the total number of the cruises that every vessel has fulfilled during 6 months can easily be determined too.

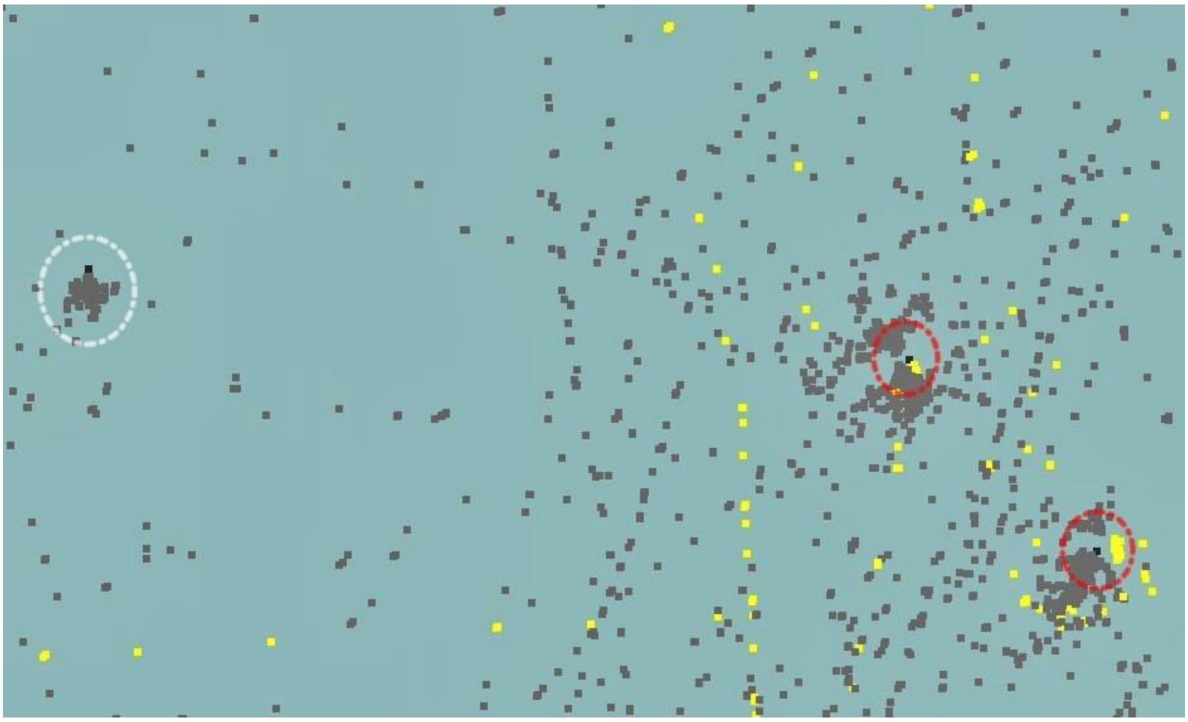

Figure 24. The visited offshore production sites during one of the cruises.

Furthermore, by using this approach it is possible to determine each offshore production site that has been visited by each PSV and each crude oil tanker in each of their cruises during 6 months. Figure 24 provides information about this mentioned determination. 2 of the visited offshore production sites, as shown here for a certain cruise which has been fulfilled by a PSV, can be seen inside the red circles at the right side of Figure 24.

The yellow record points around the black point inside the red circles shows that the PSV has performed the loading – unloading operation onto these 2 offshore production sites during this certain cruise.But the vessel has not been performed any logistics operation onto the other offshore production site during this cruise.This can be seen inside the white circle at the left side of Figure 24. Since there are not any yellow record points inside the white circle but only grey record points, it can be understand that this PSV has visited that offshore production site during another cruise.

K	Q	R	S	U	X
MOVEMENT_STATUS	X (km) - Long	Y (km) - Lat	ZONE	OPERATION_STATUS	CRUISE_STATUS
Waiting	-4474,572804	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,595043	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,595043	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,572804	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,595043	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,595043	-2588,434398	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,595043	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,591707	-2588,431988	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,572804	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,595043	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,600603	-2588,429578	P_48	Loading/Unloading - Platform	Journey 23
Waiting	-4474,595043	-2588,415118	P_48	Loading/Unloading - Platform	Journey 23

Figure 25. A screenshot from the excel solver.

Figure 25 provides the information regarding to loading – unloading operation onto P-48 offshore production site that has been performed by a PSV on its 23th cruise. At K column, the movement status of the vessel can be seen as "Waiting" and at Q and R columns the location of the vessel can be seen as Cartesian coordinates for the each signal. From the S column it can be understand that these coordinates correspond to the zone of P-48 offshore production site. Since the vessel in under "Waiting" status and inside of P-48 zone, she has been performing the loading – unloading operation at that time, as can be seen at the U column. In addition to this, at the X column it can be seen that this logistics operation has been performed on 23th cruise of that PSV.

Therefore, by using the information about the visited offshore production sites per cruise for each PSV and each crude oil tanker that has been analyzed, it is possible to determine the frequency of visit of each offshore production site. Also it gives an option to determine the total number of visits of each offshore production site for a set period. Table 2 provides information about this determination;

Table 2. Frequency of visit.

Type of Offshore Production Site	Frequency of PSV (s)	Frequency of Crude oil tanker (s)
Fixed Platform	144000 (1.67 days)	864000 (10 days)
SS	185143 (2.15 days)	864000 (10 days)
FPSO	216000 (2.5 days)	864000 (10 days)

As shown at table 2, the frequency of visit for each type of offshore production site has been determined by using the information regarding to the total number of visits by each type of vessel during 6 months. Since the simulation software is working with seconds as a unit, frequency values have been calculated as seconds to make the implementation properly.

3.4. Implementation of Analyze Results

3.4.1. Obtained Information

By using the algorithm that has been explained in the previous sections, A.I.S. signals of 75 PSVs and 15 crude oil tankers have been analyzed one by one. Also by observing the change in time, in the status of vessels and in the behavior of vessels, following information has been obtained as the result:

- Duration (seconds) of each loading – unloading operation at each port that has been performed by each PSV,
- Duration (seconds) of each loading – unloading operation at each offshore production site that has been performed by each PSV,
- Duration (seconds) of each loading – unloading operation at each port that has been performed by each crude oil tanker,
- Duration (seconds) of each loading – unloading operation at each offshore production site that has been performed by each crude oil tanker,
- Duration (seconds) of each mooring at each mooring zone that has been performed by each PSV,
- Duration (seconds) of each mooring at each mooring zone that has been performed by each crude oil tanker,
- Elapsed time (seconds) under waiting status for PSV,
- Elapsed time (seconds) under waiting status for each crude oil tanker,
- Velocity (knots) information in each signal under sailing status for each PSV,
- Velocity (knots) information in each signal under sailing status for each crude oil tanker,
- Total number of cruises for each PSV,
- Total number of cruises for each crude oil tanker,
- Total number of visits to each offshore production site per cruise by each PSV,
- Total number of visits to each offshore production site per cruise by each crude oil tanker.

So with all these information that have been obtained from the analysis, several distributions have been taken to be able to determine the relevant variables of stochastic simulation. But before creating the distributions, a box plot outlier test has been applied to each data and abnormal values have been detected and distinguished from usage into distributions.

All the distributions have been created by using EasyFit software. For each type of ship, each type of operation and each type of status, different histograms have been created. In order to determine the type and specification of distributions, individual distribution identification is executed by using the same software. Most of the distributions that have been suggested by the software were not applicable, due to the reason that they are not pre-defined in the simulation software. Thus, the best fitting distribution has been chosen, according to the available pre-defined distribution options, from the simulation software.

3.4.2. Platform supply vessel related distributions

Six months of A.I.S tracking data for 75 PSVs have been investigated and the relevant distributions that have been obtained are given below on figures;

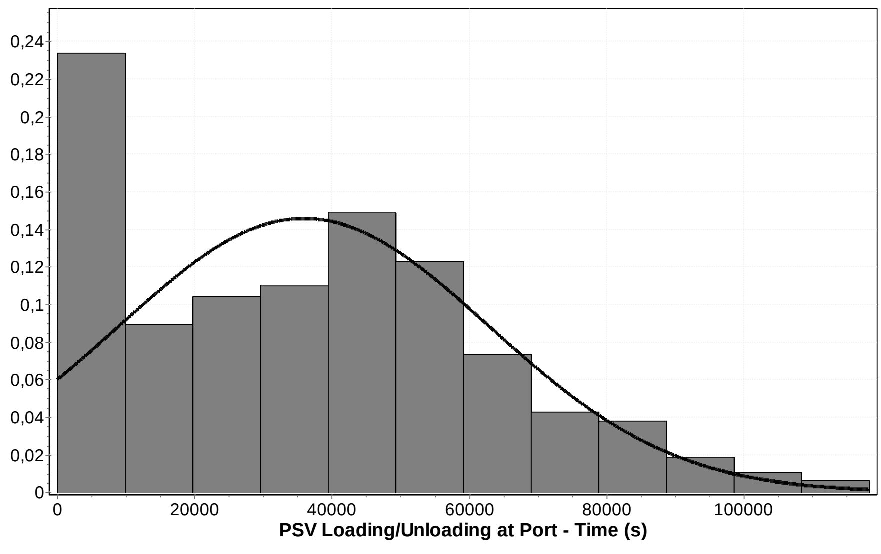

Figure 26. The total time of loading – unloading operations performed by PSVs at ports.

The histogram of the duration of loading – unloading operations that have been performed by PSVs at several ports is presented on Figure 26. The best fitting distribution that has been observed as Normal distribution among the others and the distribution has been set with 35962 as mean and 26943 standard deviation values.

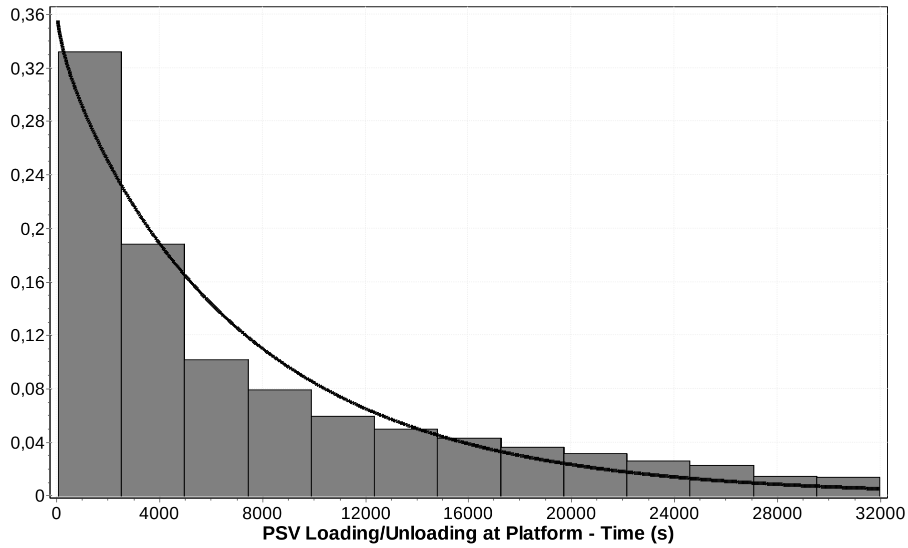

Figure 27. The total time of loading – unloading operations performed by PSVs at offshore production sites.

The histogram of the duration of loading – unloading operations that have been performed by PSVs at several offshore production sites is presented on Figure 27. The best fitting distribution that has been observed as Weibull distribution among the others and the distribution has been set with 0.97592 shape and 7512.8 scale values.

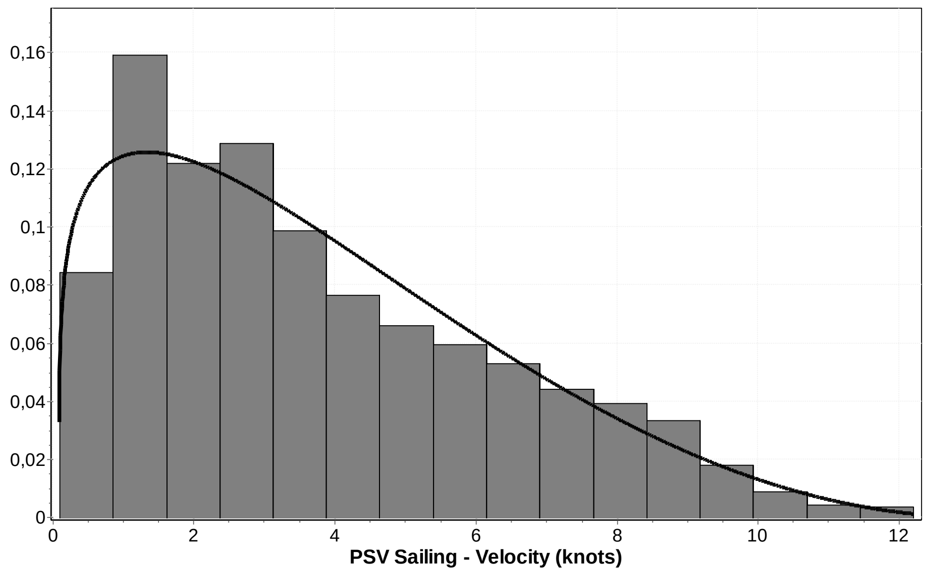

Figure 28. The velocity (knots) of PSVs during "Sailing" status.

The histogram of the velocity (knots) during "Sailing" status for PSVs is presented on Figure 28. The best fitting distribution that has been observed as Beta distribution among the others and the distribution has been set with 1.2156 shape and 3.0611 scale values.

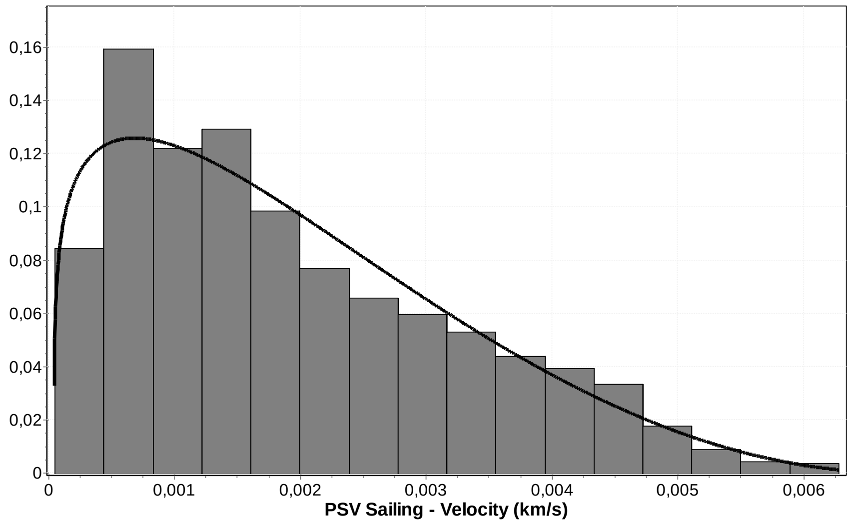

Figure 29. The velocity (km/s) of PSVs during “Sailing” status.

Since the simulation software works with second as a unit, “Sailing” status values have been converted from knots to km/s. The histogram of the velocity (km/s) during “Sailing” status for PSVs is presented on Figure 29. The best fitting distribution that has been observed as Beta distribution among the others and the distribution has been set with 1.2159 shape and 3.0652 scale values.

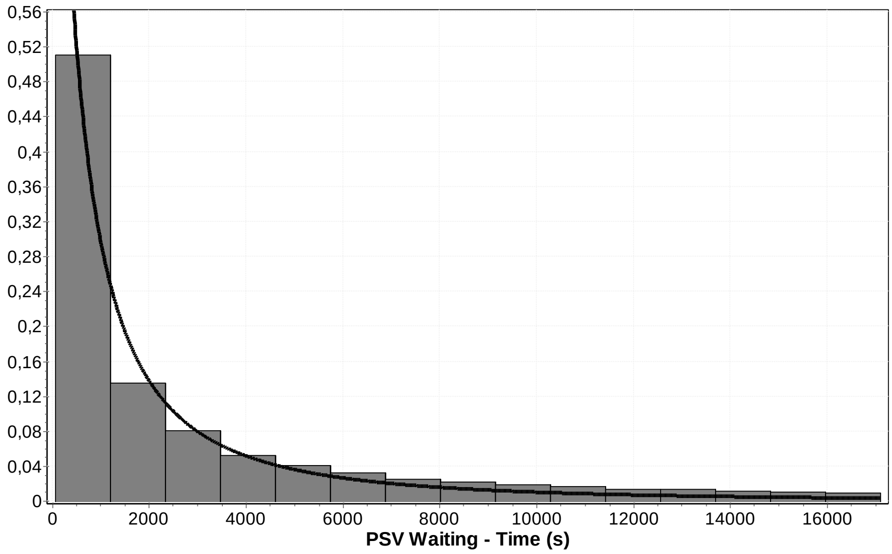

Figure 30. The total elapsed time under “Waiting” status for PSVs.

The histogram of the total elapsed time under “Waiting” status for PSVs is presented on Figure 30. The best fitting distribution that has been observed as Lognormal distribution among the others and the distribution has been set with 3466.6 mean and 10419 standard deviation values.

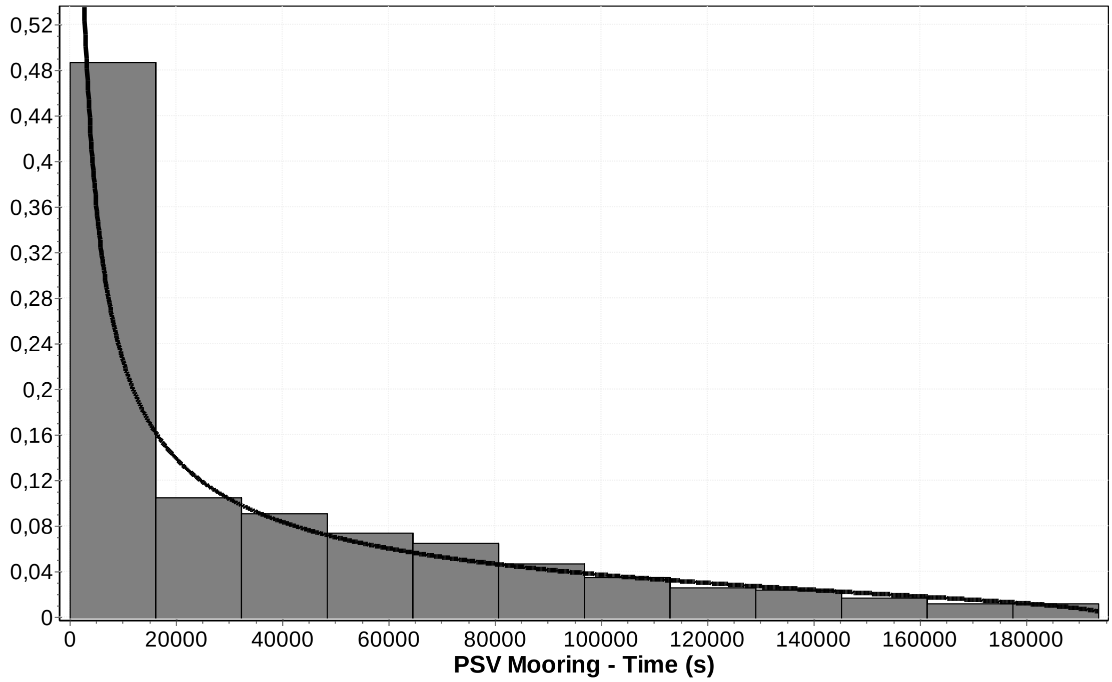

Figure 31. The total elapsed time during mooring for PSVs.

The histogram of the total elapsed time under "Mooring" status for PSVs is presented on Figure 31. The unit of the histogram defined as seconds. The best fitting distribution that has been observed as Beta distribution among the others and the distribution has been set with 0.33515 shape and 1.4062 scale values.

The unit of all elapsed time and duration related histograms are seconds for both types of vessels; PSV related distributions and crude oil tankers related distributions.

The unit of all velocity related histograms is km/s for both types of vessels; PSV related distributions and crude oil tankers related distributions.

3.4.3. Crude oil tanker related distributions

6 months of A.I.S tracking data for 15 crude oil tankers have been investigated and the relevant distributions that have been obtained are given below on figures;

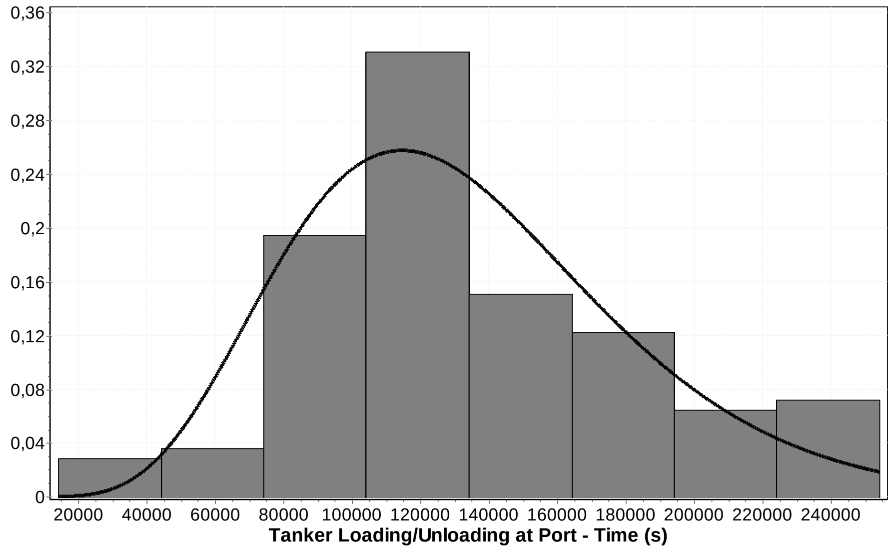

Figure 32. The total time of loading – unloading operations performed by crude oil tankers at ports.

The histogram of the duration of loading – unloading operations at several ports performed by crude oil tankers is presented on Figure 32. The best fitting distribution that has been observed as Gamma distribution among the others and the distribution has been set with 7.245 shape and 18366 scale values.

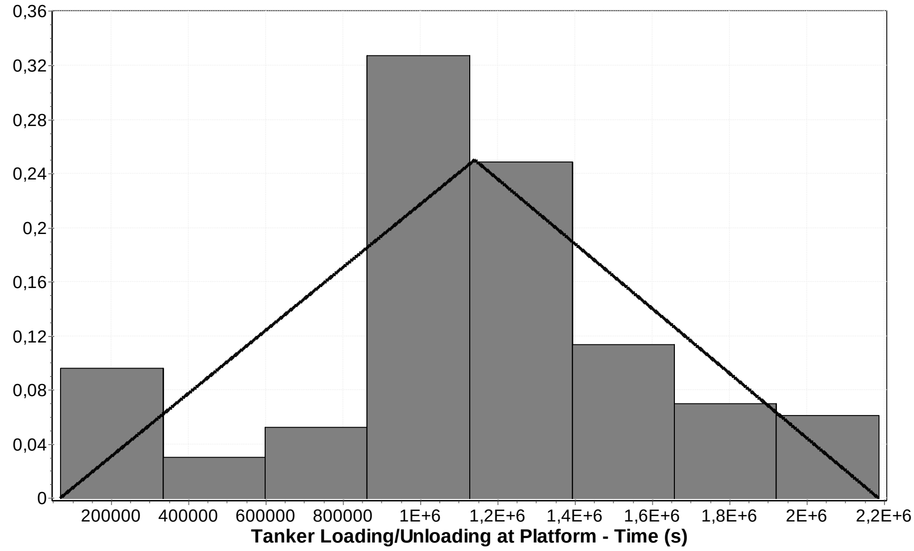

Figure 33. The total time of loading – unloading operations performed by crude oil tankers at offshore production sites.

The histogram of the duration of loading – unloading operations at offshore production sites performed by crude oil tankers is presented on Figure 33. The best fitting distribution that has been observed as Triangular distribution among the others and the distribution has been set with 67620 minimum, 1140600 mode and 2185900 maximum values.

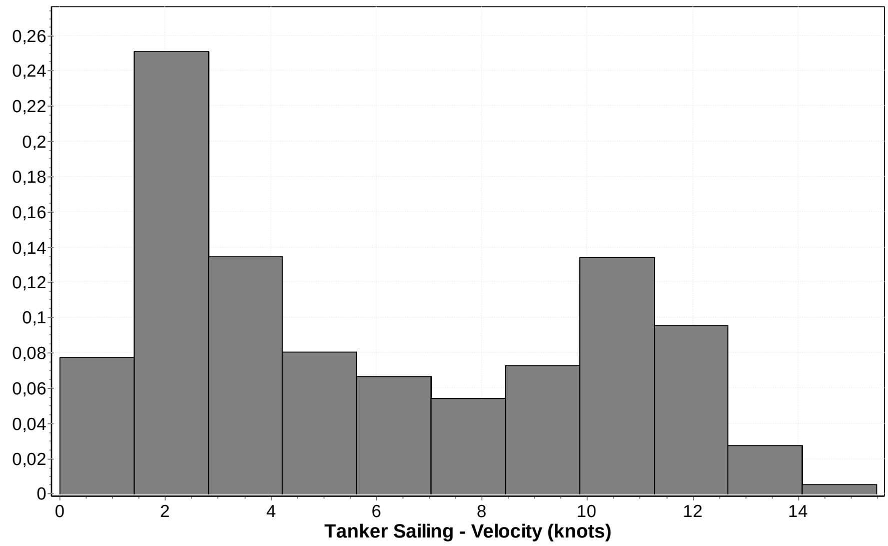

Figure 34. The velocity (knots) of crude oil tankers during “Sailing” status.

The histogram of the velocity (knots) during “Sailing” status for crude oil tankers is presented on Figure 34. But also can be seen the distribution has two peaks and that kind of distribution is called as bipolar distribution. Also as it mentioned before, the best fitting distribution suggestion of EasyFit software was not applicable neither for the simulation software. Therefore the distribution has been divided into two separate parts by separating the values from each other and in each part different values have been used to avoid the conflict. The value that has been used in the first divided part has not been used into second divided part and the values of two separate distributions have been summed up in simulation software. Also the values have been converted to km/s from knots for each part, as shown on Figure 35.

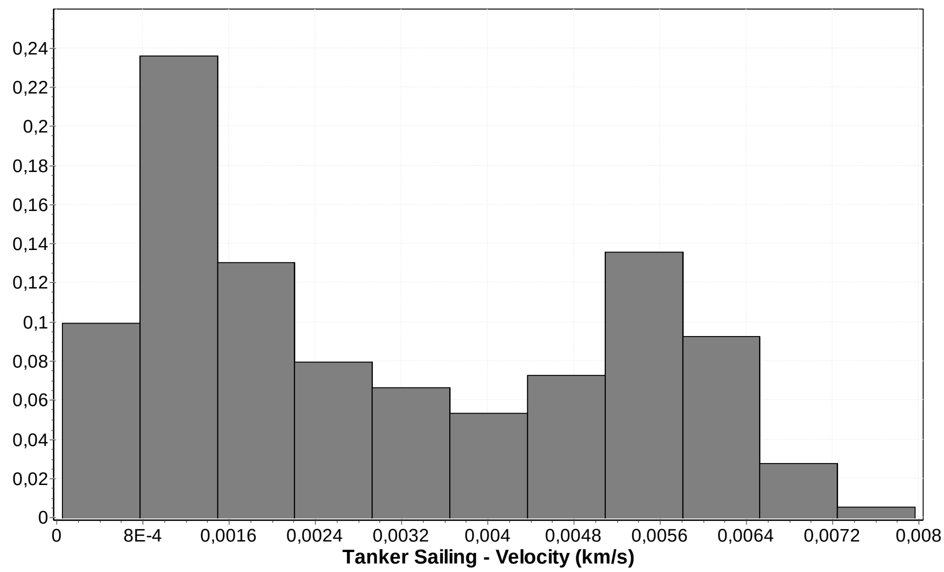

Figure 35. The velocity (km/s) of crude oil tankers during “Sailing” status.

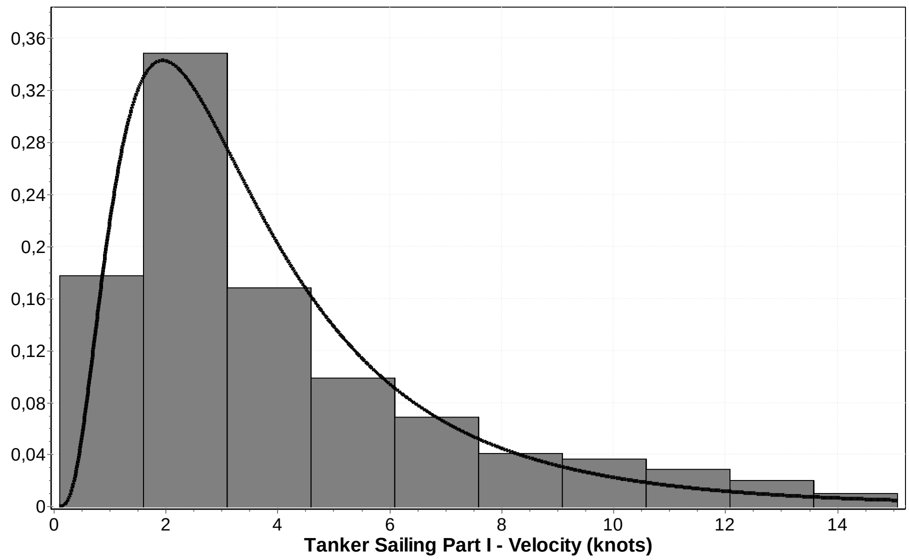

Figure 36. The first part of velocity (knots) of crude oil tankers during “Sailing” status.

The histogram of the first part of velocity (knots) during “Sailing” status for crude oil tankers is presented on Figure 36. The best fitting distribution that has been observed as Lognormal distribution among the others and the distribution has been set with 4.0651 mean and 3.2322 standard deviation values.

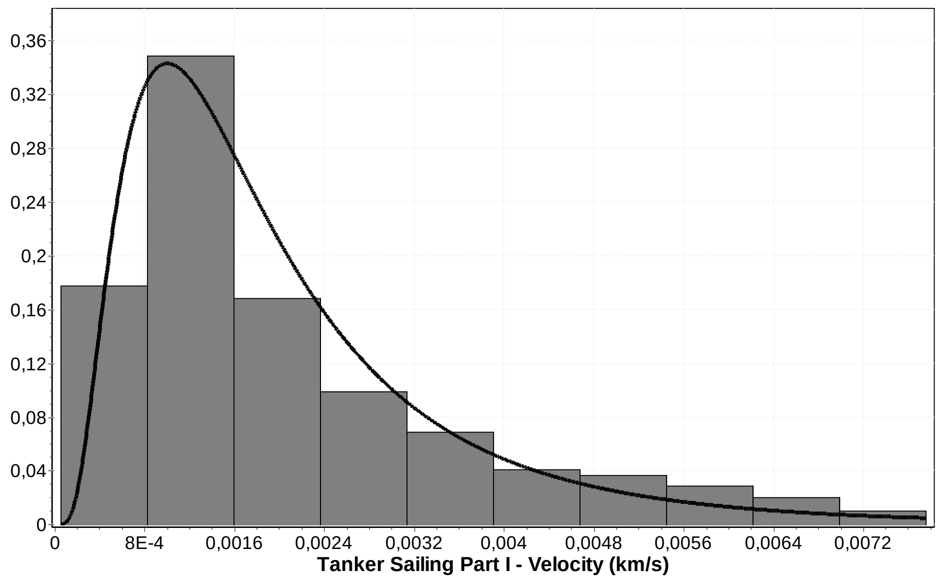

Figure 37. The first part of velocity (km/s) of crude oil tankers during “Sailing” status.

The histogram of the first part of velocity (km/s) during “Sailing” status for crude oil tankers is presented on Figure 37. The best fitting distribution that has been observed as Lognormal distribution among the others and the distribution has been set with 0.00209 mean and 0.00166 standard deviation values.

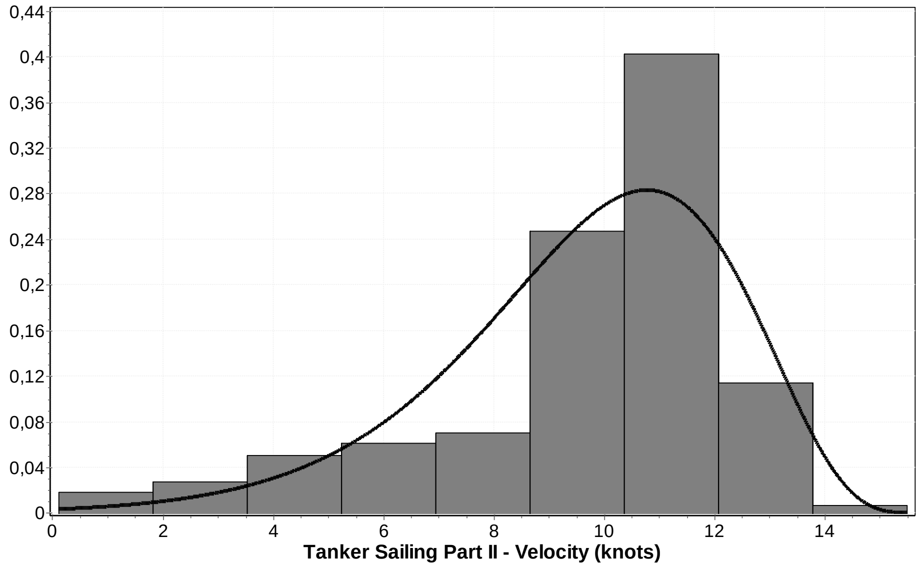

Figure 38. The second part of velocity (knots) of crude oil tankers during “Sailing” status.

The histogram of the second part of velocity (knots) during “Sailing” status for crude oil tankers is presented on Figure 38. The best fitting distribution that has been observed as Beta distribution among the others and the distribution has been set with 15698000 shape and 5.4772 scale values.

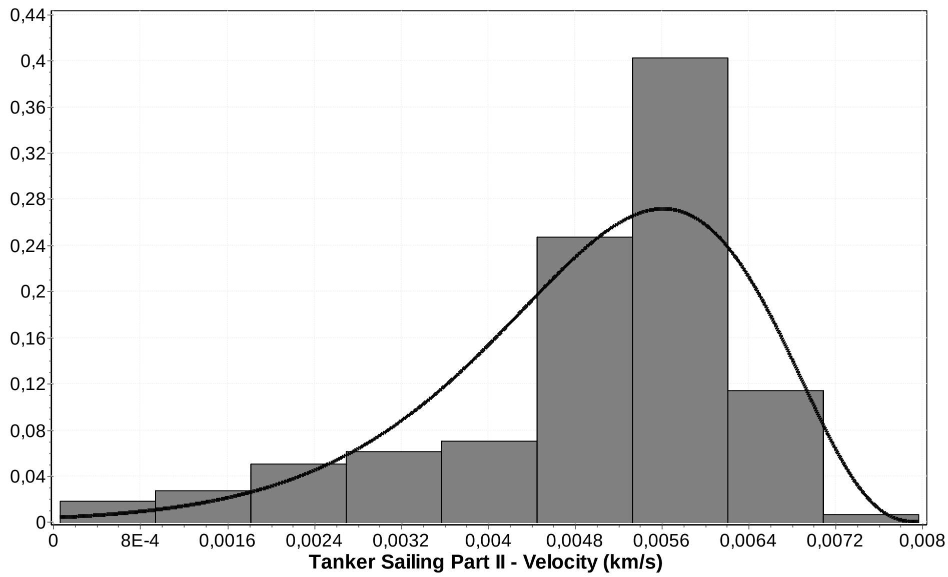

Figure 39. The second part of velocity (km/s) of crude oil tanker during “Sailing” status.

The histogram of the second part of velocity (km/s) during “Sailing” status for crude oil tankers is presented on Figure 39. The best fitting distribution that has been observed as Beta distribution among the others and the distribution has been set with 101.2 shape and 4.5168 scale values.

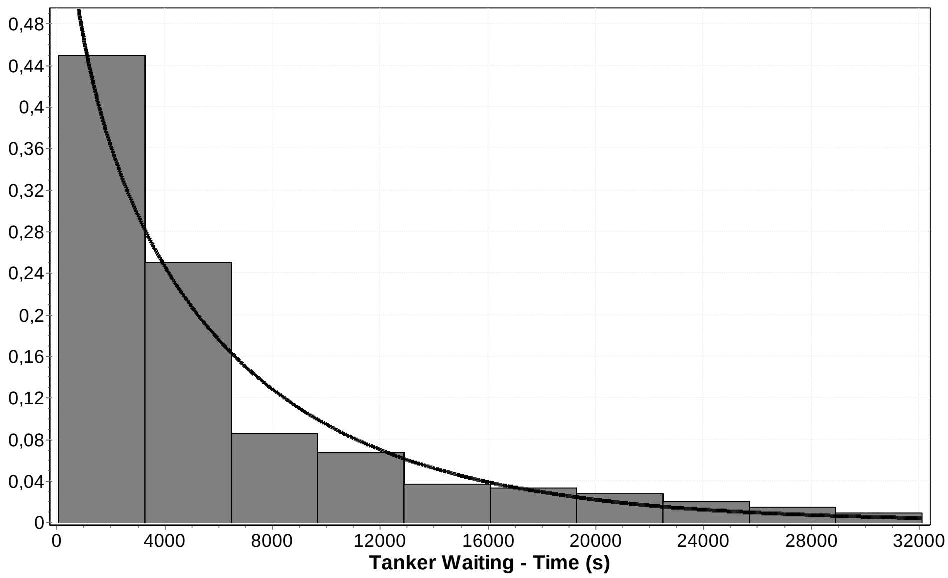

Figure 40. The total elapsed time under “Waiting” status for crude oil tankers.

The histogram of the total elapsed time under “Waiting” status for crude oil tankers is presented on Figure 40. The best fitting distribution that has been observed as Gamma distribution among the others and the distribution has been set with 0.83199 shape and 7435.3 scale values.

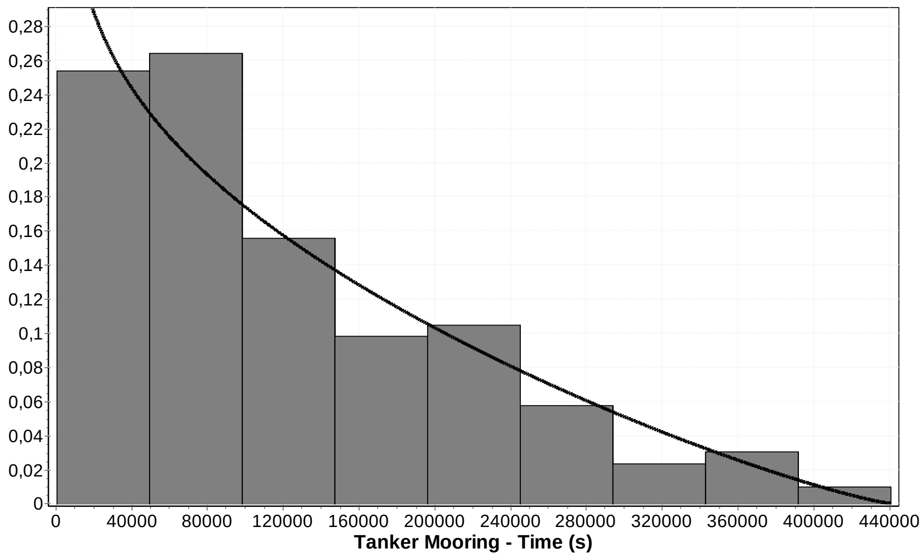

Figure 41. The total elapsed time during mooring for crude oil tankers.

The histogram of the total elapsed time under “Mooring” for crude oil tankers and is presented on Figure 41. The best fitting distribution that has been observed as Beta distribution among the others and the distribution has been set with 0.844 shape and 2.1937 scale values.

4. SIMULATION

4.1. Methodology

Simulation is one of the most broadly used operation research and decision modeling techniques. As an indication to this, COMPIT (Conference on Computer Applications and Information Technology in the Maritime Industries) and Winter Simulation Conference can be shown and both of them attracts 500 to 700 people every year. It is not possible to bring an accurate description by a mathematical model which can be evaluated analytically to the complex real-world systems which includes stochastic elements. This is one of the main reasons for such popularity of simulation.

The essential obstacles preventing the simulation from becoming a globally accepted and well-utilized tool are the time for model development and the modeling skills required for the development of a prospering simulation. All of the mentioned previously show that this study is not only contemporary and interesting, but also quite complex and demands time as well as particular skills to be successful and practical.

Simulation is a technique to mimic the operations of real world facilities or processes by using computers. These facilities or processes of interest are usually called as system. In order to study it scientifically, it is generally required to make some assumptions about how it works. These assumptions take places as mathematical or logical relationships and establish a model that identifies the behavior of the system. If these relationships are ordinary enough and uncomplicated, it is possible to use mathematical methods to analyze the system. However, most of the systems in the real world are too complex to be analyzed analytically so that's why these systems need to be studied as means of simulation.

According to Kelton et al. [21] simulation refers to an extensive collection of methods and applications to imitate the behavior of real systems, mostly on computers with appropriate softwares. A system is defined as a collection of several entities (vessels and offshore production sites) that act and interact together towards the accomplishment of some logical end. According to that definition, the logistics process of the offshore production sites is the system that has been studied in this thesis. The PSVs and crude oil tankers during their routes

can be seen as the entities that act and interact together. And the purpose is the successful delivery of supplies and oil to the offshore production sites and onshore.
Systems can be divided into two types: discrete and continuous. A discrete system is the one in which the state variables change instantaneously at separated points in time and in a continuous system state variables change continuously with respect to time. A few of the systems in practice are completely discrete or continuous, but since one type of change predominates for most systems, it is usually possible to classify a system as being either discrete or continuous. In this thesis the system is a discrete system as state variables.

According to Law and Kelton [21] a stochastic Discrete-Event Simulation models a system whose state may change only at discrete points in time. That means discrete-event simulation contains probabilistic parameters. Such as inter-arrival times and service times are random variables and these variables have cumulative distribution functions which have been shown and explained in chapter 3.4. So the main advantage of DES is the consideration of random factors that has impact on the operation of the system. It provides a stochastic modeling where the uncertainties of each process have been considered by usage of different random variables. As example for a logistic activity, decisions of the vessel's captain, equipment that has been using in the loading – unloading operation and weather condition related randomness can be introduced by using statistical data thus making it possible to create a system model to obtain more accurate and precise results.

Moreover, DES has another several major advantages compared to other simulation methods. First of all, it takes into account the simulated system in dynamics, considering its own evolution through the time. In addition to this, discrete-event simulation gives a better option to the user to understand the attributes of the observed system. It gives fair results about the obstacles in the processes in terms of saving time and improving quality.

Furthermore, it gives another option to the user to apply different approaches or strategies by using other possible variations, to see new outcomes and make comparison. User can simply determine the most feasible way to apportion the resources and work load. Along with that, DES makes it possible to observe the effects of modified inputs for the optimization, i.e. vessels' routes vessels' velocity can be analyzed with a specified future works. Because studying the impact of changes in the system by a simulation is less expensive than altering an existing system.

4.1.1. Assumptions and simplifications

In order to conduct the simulation assumptions and simplifications have been set;

- Each PSV is identical, each of them has same dimensions and same load capacity, using same related distributions.
- Each crude oil tanker is identical, each of them has same dimensions and same load capacity, using same related distributions.
- Each FPSO (Floating Production, Storage and Offloading) is identical, each of them has same dimensions and same production capacity, using same related distributions.
- Each fixed platform is identical, each of them has same dimensions and same production capacity, using same related distributions.
- Each SS (Semi-submersibles) is identical, each of them has same dimensions and same production capacity, using same related distributions.
- Each crude oil tanker port is identical, each of them has same systems for unloading processes of oil and same storage capacity.
- In simulation, the surface of earth is flat instead of curved with the radius of earth.
- Vessels are cruising on a straight route, not on a specified route.
- The distance that crude oil tankers cover to the offshore production sites during the loading – unloading operations due to their loading – unloading operation procedure were not taken into account.
- Weather conditions between April and October were included in the distributions naturally but since the analyzed database has 6 months of data, all seasons of a yearwere not taken into account,
- Minuscule swift into the exact locations of offshore production sites due to the transformation from longitude – latitude to the Cartesian coordinates (x-y) were not taken into account.

4.2. Structure of Research

The purpose of this study is to create a simulation, which enables to study in logistics activities of offshore production sites. In order to do this, the information that have been obtained via database and previous researches about similar subjects, have been combined with the amenities of simulation technology. In order to present this association, this section is dedicated to explain the structure of the research that has been done.

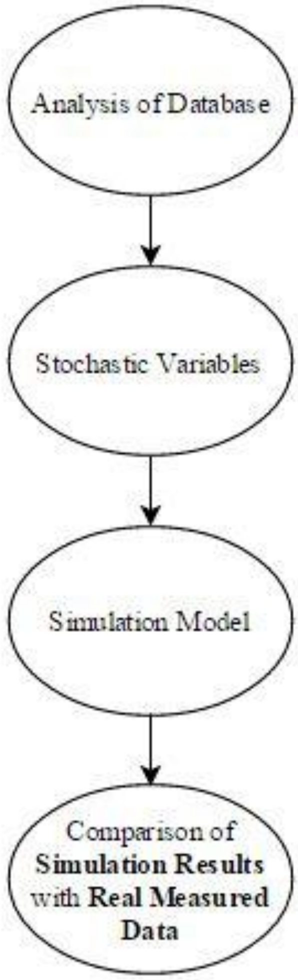

Figure 42. Structure of Research.

The formation of the structure of simulation can be seen on Figure 42. After the analysis of the database and the creation of stochastic variables, the simulation model have been created as third step. In order to create the simulation model, the elements of simulation have been defined according to the implementation of simulation.

4.2.1. Creation of simulation model

The simulation model has been created with DES (Discrete-Event Simulation) software which is called as QUEST (Queuing Event Simulation Tool). It is a powerful tool that has been developed by Dassault Systems. A brief explanation about the formation of the simulation has been given in this chapter to provide a clear comprehension.

QUEST allows the users to work with Graphical User Interface (GUI) in order to build the simulation model. This feature provides useful options to the user such as designing and visualizing the 3D animation of the model itself. In addition, one of the advantages of this feature is to enable the user to follow the work on process and detect potential errors regarding to simulation visuality. During the preparation of this simulation, the vessels and offshore platforms, movements of vessels, performed operations, location of ports and offshore production sites have been checked basically by using GUI.

Moreover, it provides an appropriate way for the explanation of the progress behind the simulation by capturing screen shots and videos from the different phases of simulation. Although GUI can be useful for the basic simulation models, it is not that practical to define advanced specifications for complex and substantial conditions. Since massive amount of data needed to be implemented into the simulation to be able to model the entire offshore logistics activity, it was not feasible to do it by using GUI. That’s why the whole simulation model has been produced by using the Simulation Control Language (SCL).

SCL is the procedural coding language of QUEST which gives an option to the user to compose the process logic to manage all the actions and behaviors of all the items in the simulation model. Decision-making activities that happen at certain times can be an example to this process logic. Such as, commanding to a crude oil tanker to move an offshore production site to perform a loading – unloading operation. Even though there are some existing process logics as pre-defined in the software, for this kind of specific simulation case, some new process logics needed to be defined. In addition to that, several Batch Control Language (BCL) commands have been used in these SCL files. They have been used to create new elements, define the features of created elements or change these features. As an example, a PSV can be created with all specifications such as velocity, accelerations, dimensions, colors by using its own data file, and also it can be changed during the simulation

4.2.2. Description of simulation model

The simulation model has been created parametrically. As can be seen on Figure 43, the model contains different modules respecting to the different properties of the simulation. This structure can be seen as ”Lego” blocks in terms of functionality such as they can be removed or can be changed with new features according to the requirement of user due to the case of simulation.

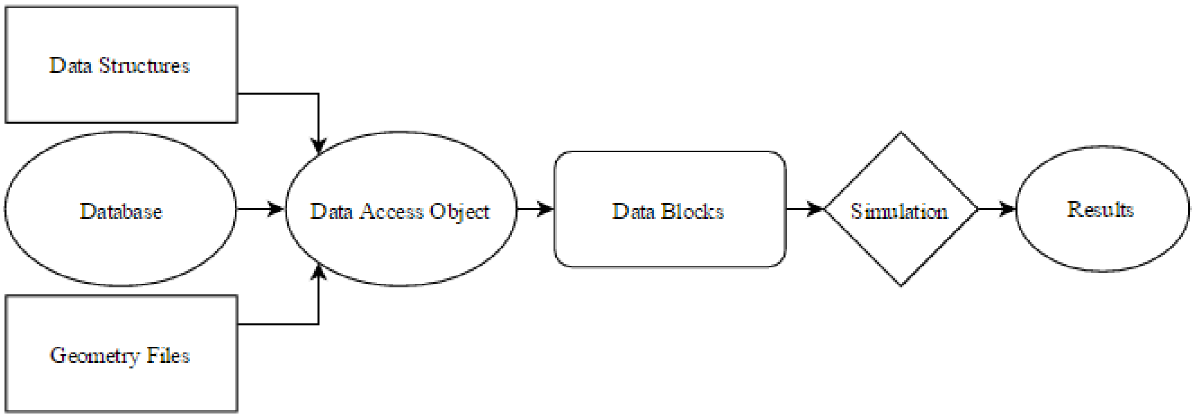

Figure 43. The structure of the Simulation Model.

The setup of entire simulation model in the software has been designed to be loaded with only one user-defined button. This one-button-triggered loading process has been taken around 25 minutes for the study case with Intel i7-3630CM 2.4 GHz GPU 12 GB RAM.

a. Database

Database has been created to load the model which involves all the elements of the simulation. Data files are in the *csv (comma-separated values) file format which can be basically defined as Excel files which contains the different specifications for different types of data. It contains all the data files for defining the numerical and physical properties of elements that has been used in the simulation such as the ships, the ports, the offshore production sites, the mooring zones and the processes.

Also this database contains two more elements which are the representative entities of simulation model. The well is a representative entity that creates the parts and releases them into simulation and the sink is another representative entity that collects the processed parts for their issue.

b. Data Structures

Data structure is the file that brings convenience into the coding process. An individual data structure has been created in order to define each column in each data file. Data structure is an *inc (include) file format which can be called from the Data Access Object's (DAO) by their names to save the user to define all the parameters again.

c. Geometry Files

Geometry file is the file that defines the 3D elements in the model of simulation. All the PSVs, crude oil tankers and offshore production sites such as fixed platforms and FPSOs are the main 3D geometries that have been used in this simulation model.

d. Data Access Object (DAO)

DAO can be called as a tool of the simulation to read and charge the data inside the model. They have been created for each data file that has been used in the simulation model.

e. Data Blocks

Data Block is the file that holds each kind of process logic for the corresponding element. In data blocks, user is able to define the tasks and functions. Source is one of the main data blocks that have been used in simulation.

Source is an element of simulation which is responsible of creating the parts and places them into their initial location before simulation starts. In this simulation, the ports and the well of the offshore production sites are the sources.

The objects database file (Objects.csv) includes the objects that have been created such as all the ports at their real locations, all the offshore production sites with their real locations and their sinks, the mooring zones and the well. Furthermore, every port in the model has to be connected with every offshore production site and every offshore production site has to be connected with its own sink and with the well, so that the model can work. For all these connections another excel database file (Objects_Connection.csv) has been created.

However, the mooring zones have not been connected to any object because they have been inserted into the simulation model as "Labor Park". That term defines the specified area where the idle labors are waiting for the next command. In this model the labors are the vessels of simulation. So when one of the vessels that has been done with the loading – unloading operation on any port or offshore production site, that vessel becomes idle in the simulation and goes to one of these mooring zones in a cyclic order to wait for the next command from port or offshore production site.

Moreover another Excel database file (Vessel.csv) has been created for the vessels that have been participated into model. That file includes the following information:

- Total number of PSVs and crude oil tankers,
- Velocity distribution values under "Sailing" status for each type of vessel,
- Time distribution values under "Waiting" status for each type of vessel,
- Time distribution values under "Loading – Unloading operations at ports" status for each type of vessel,
- Time distribution values under "Loading – Unloading operations at offshore production sites" status for each type of vessel,
- The carried part (freight) capacity values for each type of vessel.

The type of the simulation model is Pull type model, which means the part is only created when the sink make a request for it. As an example, if the sink of a certain offshore production site is empty at that moment, the sink requests the waste from the offshore production site to take it and when that request has been transmitted to the offshore production site, the offshore production site realizes that it needs supply, so it is transmitting the request of supply to the port and the port creates the supply. After that the port chooses the idle and the closest PSV from mooring zone to convey the requested supply to the offshore production site. When the supply arrives to the offshore production site, it generates another waste and this cycle continues in this manner for each offshore production site until the end of simulation.

In addition to this, if the other sink of the same offshore production site is empty at that moment, that sink requests the waste of oil extraction process from the offshore production site to take it and when that request has been transmitted to the offshore production site, the offshore production site realizes that it needs create crude oil, so it transmitting the request of crude oil to the well. The well generates the crude oil and transfers it directly to the offshore production site. When the extracted crude oil is ready for the transportation, the idle and the closest crude oil tanker is chosen to convey the crude oil to the specified crude oil tanker ports.

Each offshore production site in the simulation model has two processes, one of them is to transform the supplies into the waste and the other one is to transform the crude oil into the waste. The cycle time of these processes has been defined as one second because that process time does not constitute an importance.

Moreover, another important point for the sinks is their connection to the offshore platform sites. 2 sinks have 2 separate connections and because of this separate connection each sink requests different kind of part. One sink requests the waste due to the supplies and the other sink requests the waste due to the crude oil. Therefore their time distributions have been defined separately and differently by considering the total number of PSVs that worked with that offshore production site (for the sink that requests waste from supplies) and the total number of crude oil tanker that worked with that offshore production site (for the sink that requests waste from crude oil).

Inside the offshore production site processes database file (Platform_Process.csv), the distributions of requested parts for the each sink of each offshore production site has been inserted. These distributions include the following information:

- How many PSVs and crude oil tankers go to one fixed platform per month,
- How many PSVs and crude oil tankers go to one FPSO (Floating Production, Storage and Offloading) per month,
- How many PSVs and crude oil tankers go to one SS (Semi-submersibles) per month.

The supplies and the waste can only be carried by PSVs and the crude oil can only be carried by crude oil tankers.

Every time a vessel perform an operation, the simulation model saves the information of that operation in a *csv file format. That file contains the loading – unloading operations time, the type of loading – unloading operation such as supplies or oil and the exact location of the operation such as at port Macaé or at P-52 offshore production site.

As a final step, multiple iterations have been done with SCL macro. The procedure that has been defined in the codes of SCL macro by the user runs the simulation several times. For every iteration SCL macro calculates the total distance travelled for each vessel in the simulation and saves that information as another *csv file format so it can be compared and analyzed later with the real case measurements.

5. RESULTS

5.1. Case Study

The reliability of the simulation model is one of the crucial points in this study. Therefore, a case study has been created according to the obtained information from the A.I.S. database analyze. While building the case study, there was no possibility to create a huge simulation model which includes all of 190 offshore production sites around the Coasts of Brazil and also their performed logistics activities by 90 ships, due to the plenty of time consuming loading and simulating processes. Some of these 190 offshore production sites and their locations around Brazil can be seen on Figure 44.

Figure 44. Several offshore production sites around Brazilian Coasts.

Due to this cause, it has been decided to create a simulation model for the case study that needs to be efficient in terms of loading and simulating processes. In order to reach that efficiency, it was decided to select a smaller cluster of offshore production sites to validate the concept. In addition to this, the important properties and mentioned characteristics of Campos Basin (which have been explained into section 3.1) have been taken into account too. Correspondingly, the offshore logistics activities that have been performed into the Campos Basin have been chosen as a case study.

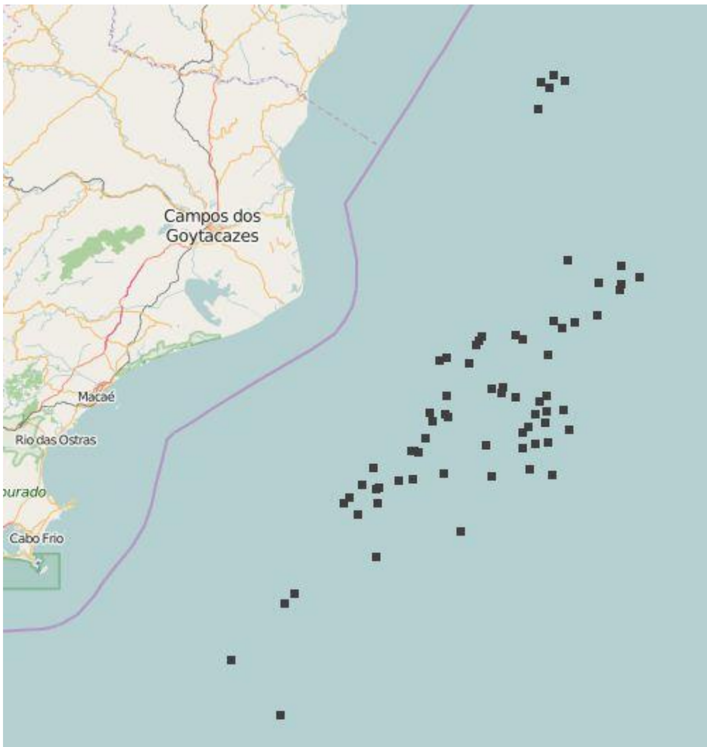

Figure 45. Offshore production sites into the Campos Basin.

Hereat, the offshore production sites that have been located only in the Campos Basin, which can be seen on Figure 45, and the vessels that have been working only with these certain offshore production sites have been modeled into the entire simulation model for the case study. The simulation model includes the following objects:

- 1 supply cargo port,
- 4 tanker ports,
- 15 crude oil tankers,
- 23 PSVs,
- 12 fixed platforms,
- 16 FPSO,
- 10 SS.

5.2. Simulation Model & Obtained Results

After the preparation of the case study model, following distribution values (which have been explained in sections 3.4.1 and 3.4.2) have been entered as stochastic parameters of the simulation model:

- Velocity under sailing status for PSVs,
- Velocity under sailing status for crude oil tankers,
- Duration under waiting status for PSVs,
- Duration under waiting status for crude oil tankers,
- Duration of loading – unloading operations at ports for PSVs,
- Duration of loading – unloading operations at ports for crude oil tankers,
- Duration of loading – unloading operations at offshore production sites for crude oil tankers,
- Duration of loading – unloading operations at offshore production sites for PSVs,

Extracted mooring distributions of PSVs andcrude oil tankers have not been implemented as variables into the simulation model to define the mooring of vessels however it has been achivied as explained in section 4.3. Figure 46 shows some of the idle PSVs and crude oil tankers during the mooring in the simulation model.

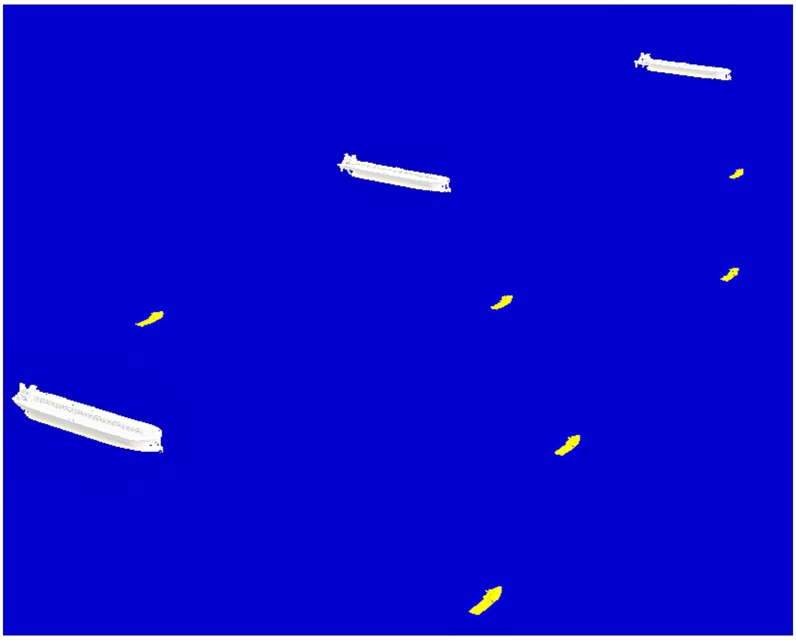

Figure 46. Some crude oil tankers and PSVs during the mooring.

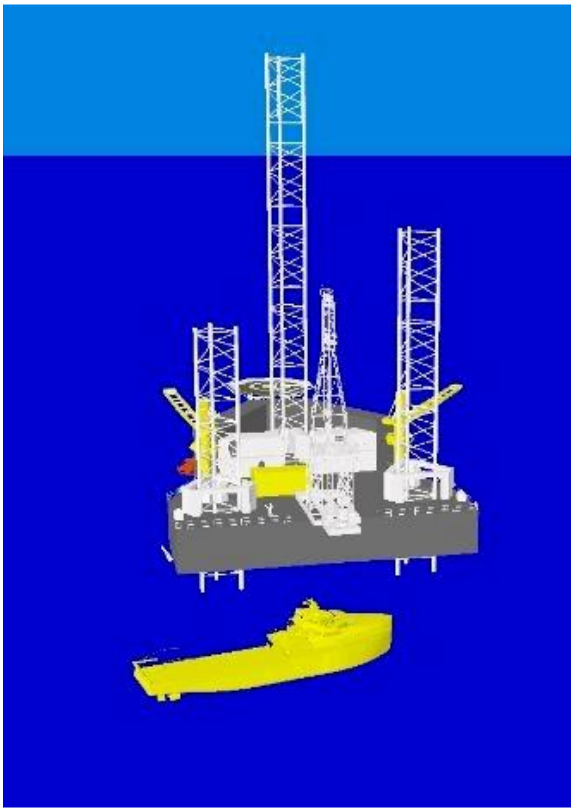

Figure 47. PSV is inside one of the fixed platform's zone.

As can be seen on Figure 47, one of the PSV is performing loading – unloading operation at one of the fixed platforms in the simulation model.

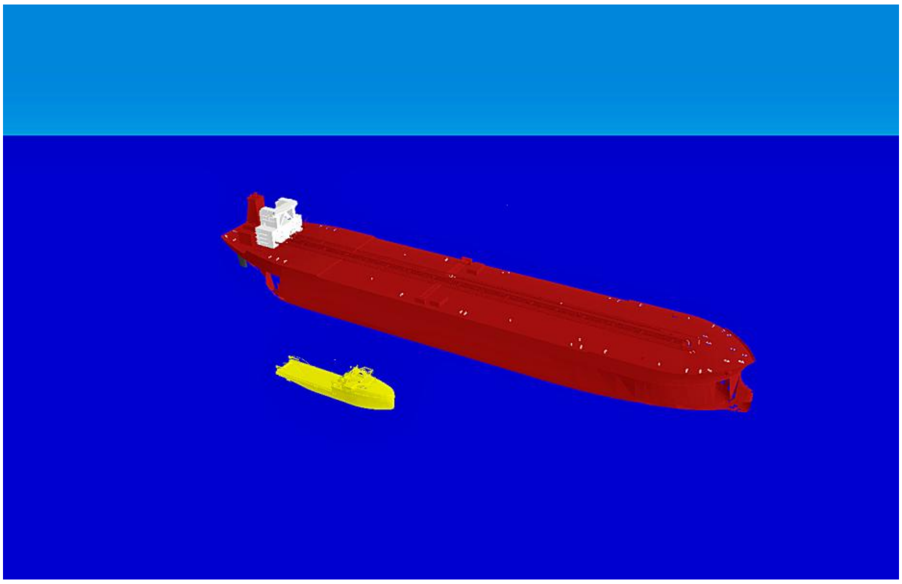

Figure 48. PSV is inside one of the FPSO's zone.

As can be seen on Figure 48, one of the PSV is performing loading – unloading operation at fixed platform.

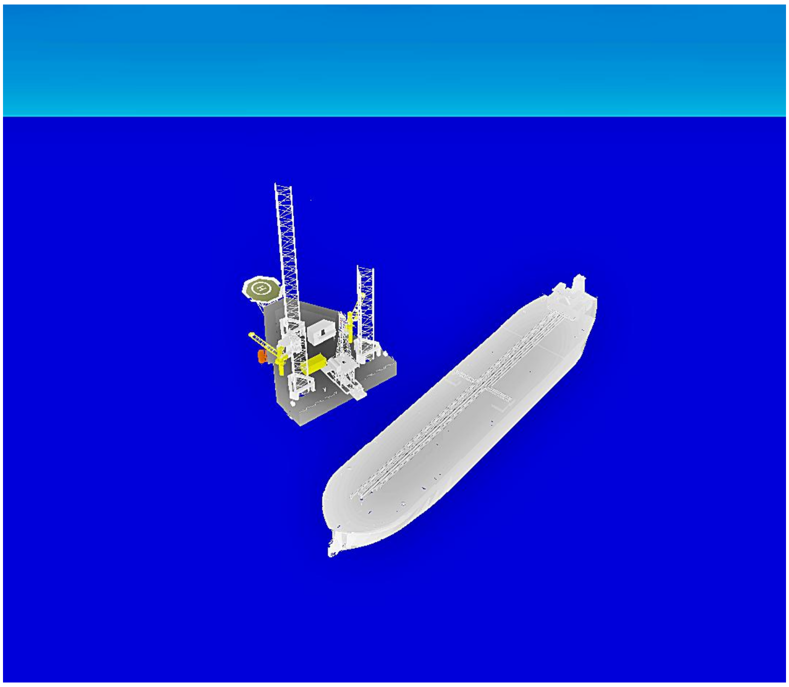

Figure 49. Crude oil tanker is inside one of the fixed platform's zone.

As can be seen on Figure 49, one of the crude oil tankers is performing loading – unloading operation at one of the fixed platforms in the simulation model.

Also as it is explained in the section 4.3., all the offshore production sites and ports that have been participated into the simulation model have been created by using their real location coordinates. Figure 50 provides information about this;

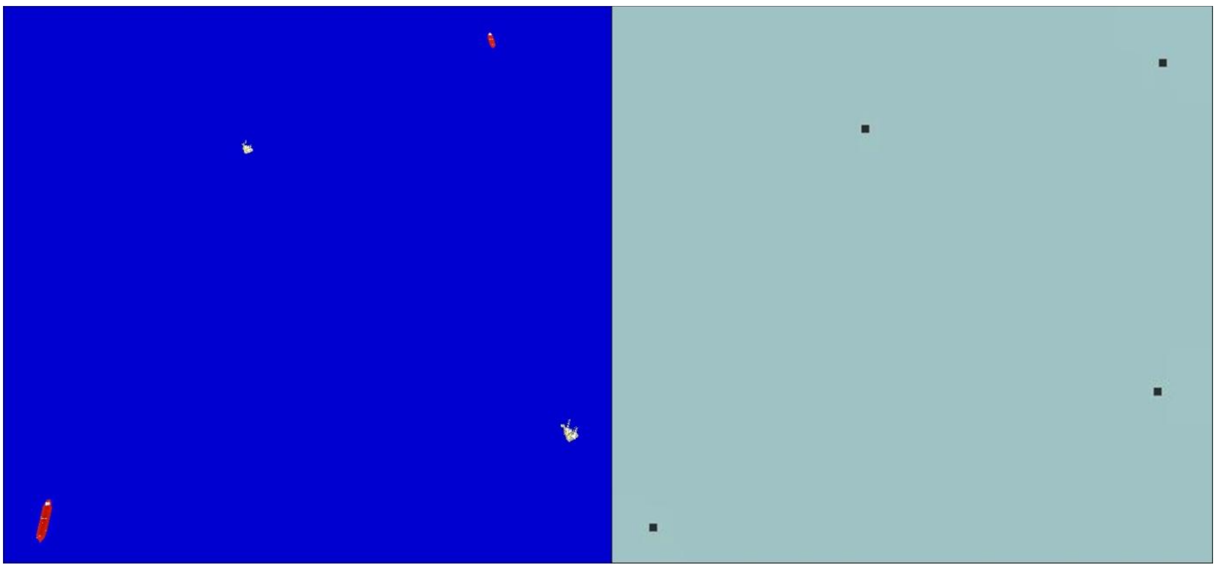

Figure 50. Global view of some offshore production sites from the simulation model (left) and from the database (right).

As it is understood from the Figure 50, all of the offshore production sites that situated in Campos basin, have been implemented with their real coordinates as they located in the real world. So it means, their distances to each other and to the ports are identical as it is real world.

Therefore, it has been decided to make a comparison of total distance traveled by all the vessels in the simulation model with the total distance traveled by all the vessels in the real world as a main crosscheck. Since, all the vessels in A.I.S. database contain information for 6 months, each iteration of the simulating process has been run with a duration of 6 months. Totally 400 iterations has been run with Intel i7-3630CM 2.4 GHz GPU 12 GB RAM and it took around 1 hour and 35 minutes.

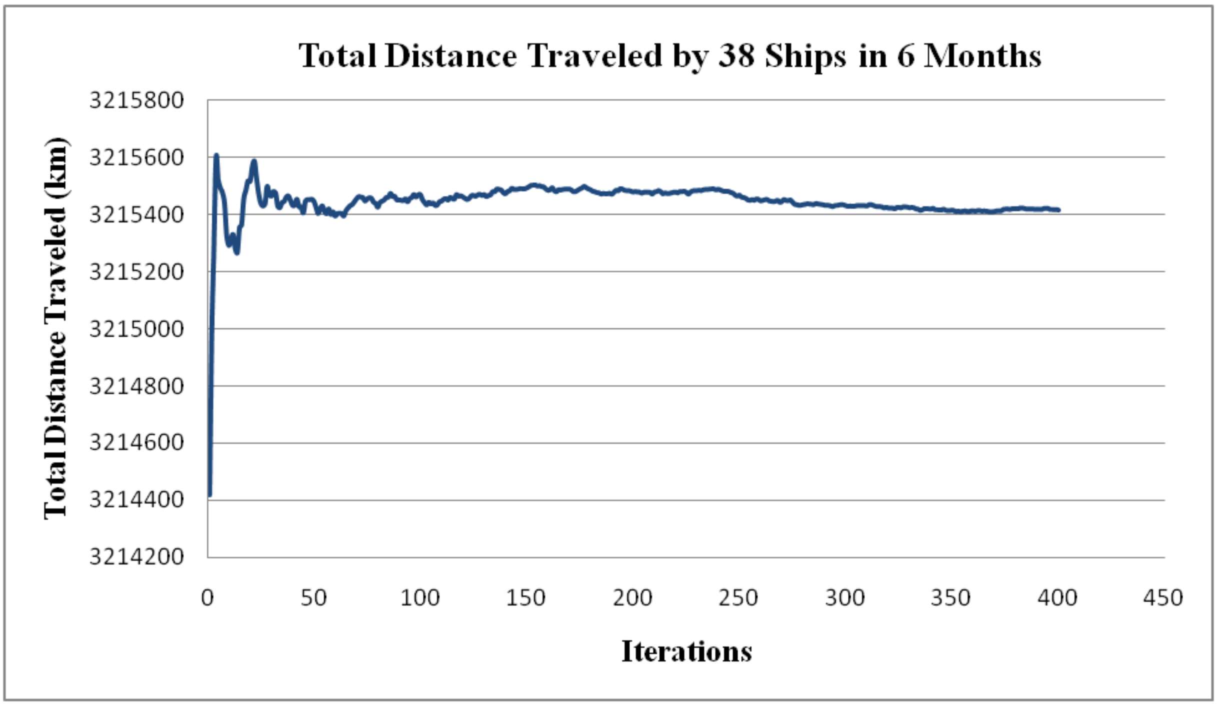

Figure 51. Convergence plot of total distance traveled in the simulation model.

As can be seen from Figure 51, SCL macro has been calculated the value of total distance traveled by 38 ships during 6 month for each iteration in the simulation model and also can be seen that it has been reached to convergence with 400 iterations.

Therefore, it can be said that the created simulation model works stable and properly and also gives logical results by using all the implemented stochastic parameters.

In order to see the accordance of the simulation model, a crosscheck has been made between the real measured data from the A.I.S. database and the result of simulation model. As it is mention on section 5.1, only certain PSVs and crude oil tankers that have been working into Campos Basin have been used in this simulation model. Hence, the distance that has been traveled by these certain vessels has been measured.

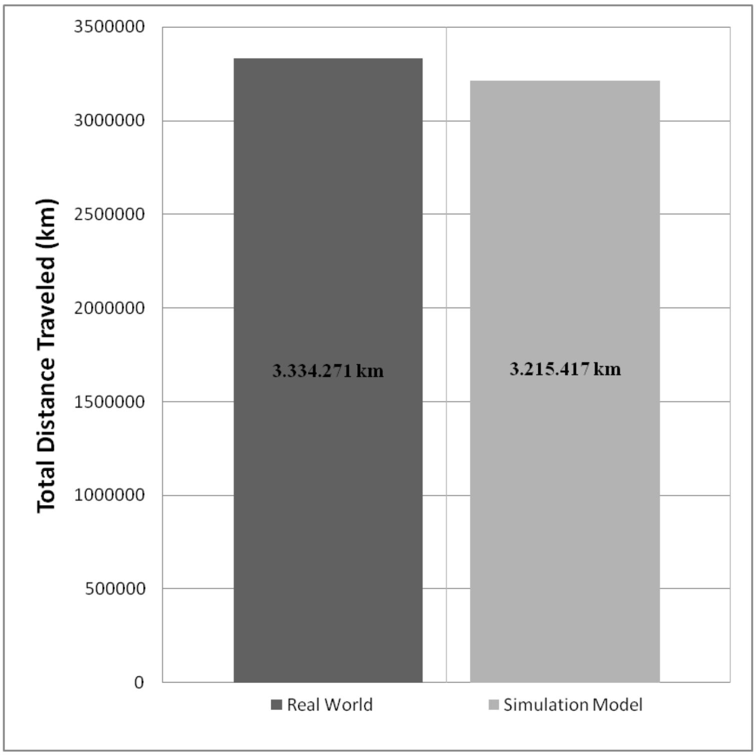

Figure 52. Comparison of total distance traveled in the real world with simulation model.

Figure 52 visualizes the comparison of results that has been measured in the real world and obtained from the simulation model. As it is understood that the results are highly close to each other so it can be said that with this provided findings the created simulation model works well according to preliminary crosscheck.

- Result of real data measurement = 3334271 km,
- Result of simulation model = 3215471 km,
- The accordance between obtained results has been measured as % 96.44.

It can be seen that according to these obtained results the error margin between the simulation results with real data measurement is only % 3.56 which can be considered quite small for such a big simulation model as this which contains 6 months of offshore logistics activity by

38 vessels and 38 offshore production sites. However, the assumptions that have been set during the preparation of the simulation model may have caused this kind of error. Also it may occured due to the utility of used software, for example the surface of earth is flat instead of curved with the radius of the earth (which have been explained in section 4.1.1.).

6. CONCLUSIONS & FUTURE WORK

6.1. Conclusions

This thesis examines the logistics activities of offshore production sites by using a stochastic approach. A parametric simulation model has been created by using Discrete-Event Simulation methodology with implementation of various properties regarding to offshore logistics activities around Brazilian Coasts.

A database which contains 6 months of A.I.S. tracking data for 75 PSVs and 15 crude oil tankers has been analyzed. In order to identify the behavior and role of each PSV and each crude oil tanker in this offshore supply chain, an algorithm has been developed. By using the developed algorithm, huge amount of data has been analyzed and different kinds of relevant information have been extracted for each type of vessel and for each type of operation. By means of these extracted information, several distributions have been taken in order to use as stochastic variables of logistics simulation of offshore production sites.

Instead of creating a massive simulation model which contains all of 190 offshore production sites around the Coasts of Brazil also with their performed logistics activities by 90 ships, it has been decided to select a smaller cluster of offshore production sites to validate the concept.Therefore, offshore logistics activities into the Campos Basin, i.e one of important coastal sedimentary basins of Brazil, has been modeled as a case study. It contains 5 ports, 15 crude oil tankers, 23 PSVs and 38 offshore production sites such as FPSO, SS and fixed platforms.

The preliminary results show a good accordance between the simulation outputs and measured data from A.I.S. database. As the main crosscheck, total distance traveled into simulation model has been compared with the real data measurement and the accordance between the results has been measured as % 96.44. There is an error margin between the obtained results as % 3.56 which can be considered quite small for such a big simulation model as this which contains too complex offshore logistics activities with 38 vessels and 38 offshore production sites during 6 months into the Campos Basin. Therefore, the reason of this error can be the assumptions that have been set during the preparation of the simulation model or it may have been occurred due to the utilities of used simulation software.

However, a more detailed database analysis can decrease this error margin and can increase the reliability of simulation model significantly. As an example, the radiuses of each specified zones for each offshore production site and portmay be tuned better and be optimized. Because the A.I.S. signals that has been sent from inside of these zones have a direct impact on determination of duration of loading – unloading operations. So if all the zones are tunedmuch better, the quality of obtaineddistributions may be improved.

Moreover, the same logic can be followed for the determination of movement of vessels such as the velocity limit which separates the movement status. This limitation may be arranged better because it also has a direct impact on the determination of operations that every vessel perform. In addition to these, more A.I.S. datafrom more vessels can be implicated into the database and extensive analyses may be done. Consequently, with more analyzed results, much more realistic distributions can be obtained to use as stochastic parameters of simulation model.

In order to sum up, it is significant that DES is a very reliable tool to inspect the offshore logistics activities but the obtained results from the simuation model are preliminary. Comparing only the total travelled distance by the vessels may not be enough to validate the created model. Comparison with speeds of ships and times of operations may also be necessary for the validation. However these kinds of comparisons could not be made due to limited time of the research. Therefore additional development and calibrations may be performed to improve the quality of the created model.

6.2. Future Work

Besides all these possible improvements, an optimization engine could be coupled with discrete-event simulation software to improve the utilization of this created model to obtain optimized results.

On the other hand, with this new approach that has been done in this study, it is highly possible to work on optimization problems regarding to the offshore logistics activities with some additional future work which varies according to specified tasks. The created simulation model may beextended to the more global cases and may be used in other O&G extraction and production areas around the world by changing the input parameters of offshore production sites and ports.

Also developed model can be adopted as a tool to examine the efficiency of existing PSV fleets or to identify the effect of different operational and management strategies in offshore logistics activities, i.e. adjusting the routes of vessels, deciding the fleet size, deciding to the uniformness of support vessel fleets in terms of efficient fuel consumption,on time operationsand optimized durations.

We suggest that DES is a reliable and useful tool to make precise analyzes and decisions in offshore logistics applications. It may bring a new scope to the improvements of offshore logistics activities.

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APPENDICES

Appendix I – Code of the developed algorithm for A.I.S. database analysis

```
Sub Calculate ()

    Dim Ship_LineAs Long
    Dim Platform_LineAs Integer
    Dim InsideCircleAs Double

Range ("S2:S90000").Select
Selection.ClearContents

Range ("U2:U90000").Select
Selection.ClearContents

Range ("V2:V90000").Select
Selection.ClearContents

Range ("W2:W90000").Select
Selection.ClearContents

Range ("X2:X90000").Select
Selection.ClearContents

Ship_Line = 2
Platform_Line = 3
    Journey = 1
    Traveling = False
    Index = 0
New_Value = 0
Old_Value = 0

    Do While IsEmpty(Cells(Ship_Line, 1)) = False

Ship_X = Cells(Ship_Line, 17).Value
```

```
Ship_Y = Cells(Ship_Line, 18).Value

    If (IsError(Ship_X) = False And IsError(Ship_Y) = False) Then

        Do While IsEmpty(ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line, 14)) = False And
IsEmpty(ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line, 15)) = False

Platform_X = ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line, 14).Value
Platform_Y = ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line, 15).Value

InsideCircle = (Ship_X - Platform_X) ^ 2 + (Ship_Y - Platform_Y) ^ 2

                If  InsideCircle<ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line,  16).Value  ^  2
Then
Cells(Ship_Line, 19).Value = ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line, 2).Value
                If (ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line, 3).Value = "Port") Then
                        If (Cells(Ship_Line, 10).Value = "Waiting") Then
Cells(Ship_Line, 21).Value = "Loading/Unloading - Port"
New_Value = "Loading/Unloading"
                            If (Traveling = True) Then
                                Traveling = False
                                Journey = Journey + 1
                            End If
ElseIf (Cells(Ship_Line, 10).Value = "Sailing") Then
Cells(Ship_Line, 21).Value = "Sailing"
New_Value = "Sailing"
                        End If
Cells(Ship_Line, 22).Value = 1
ElseIf (ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line, 3).Value = "Platform") Then
                        If (Cells(Ship_Line, 10).Value = "Waiting") Then
Cells(Ship_Line, 21).Value = "Loading/Unloading - Platform"
New_Value = "Loading/Unloading"
ElseIf (Cells(Ship_Line, 10).Value = "Sailing") Then
Cells(Ship_Line, 21).Value = "Sailing"
New_Value = "Sailing"
                        End If
Cells(Ship_Line, 22).Value = 4
```

```
                    Traveling = True
ElseIf (ActiveWorkbook.Sheets("Platforms").Cells(Platform_Line, 3).Value = "Anchorage") Then
                    If (Cells(Ship_Line, 10).Value = "Waiting") Then
Cells(Ship_Line, 21).Value = "Anchorage"
New_Value = "Anchorage"
ElseIf (Cells(Ship_Line, 10).Value = "Sailing") Then
Cells(Ship_Line, 21).Value = "Sailing"
New_Value = "Sailing"
                    End If
Cells(Ship_Line, 22).Value = 3
            End If
            End If

Platform_Line = Platform_Line + 1
      Loop

   Else
Cells(Ship_Line, 19).Value = "ERROR"
   End If

   If (IsEmpty(Cells(Ship_Line, 19)) = True) Then
      If (Cells(Ship_Line, 10).Value = "Waiting") Then
Cells(Ship_Line, 21).Value = "Waiting"
New_Value = "Waiting"
ElseIf (Cells(Ship_Line, 10).Value = "Sailing") Then
Cells(Ship_Line, 21).Value = "Sailing"
New_Value = "Sailing"
         End If
Cells(Ship_Line, 22).Value = 2
   End If

   If (Cells(Ship_Line, 19).Value <> "ERROR") Then
Cells(Ship_Line, 24).Value = "Journey " + CStr(Journey)
   End If

   If (New_Value<>Old_Value And Cells(Ship_Line, 19).Value <> "ERROR") Then
Old_Value = New_Value
```

```
        Index = Index + 1
    End If

    If (Cells(Ship_Line, 19).Value <> "ERROR") Then
Cells(Ship_Line, 23).Value = Index
    End If

Platform_Line = 3
Ship_Line = Ship_Line + 1
    Loop

End Sub
```