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Queuing scenarios in bulk terminal discharge operations in the ports of Colombia

by

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Acknowledgements

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Abstract

Port congestion is a heavy burden international trade has to deal with. Delays and loss of time add unnecessary costs and inefficiencies to the supply chain. As a consequence such detrimental conditions, act as a trade barrier for the countries or regions involved. Such condition is more critical in developing countries where constraints budget and operational capacity is limited, depending further the problematic. Research on congestion, specifically on queue formations, allows researchers to understand better each specific scenario and to formulate solutions for the improvement of congested locations.

The specific case of Colombia in South America is not an exception to the abovementioned situation. High trade volumes have been handled in this country over the last decade, increasing the traffic of vessels in and out of the ports. The particular cases of the three most important ports on the Colombian Caribbean coast Santa Marta, Barranquilla and Cartagena, are not an exception to the traffic condition. In some of the cases, high congestion scenarios occur, resulting on vessels queuing awaiting to be served by the ports. Time loss resulting from the queueing scenarios undermines the country's capacity to become more competitive and efficient. This condition must be changed in order to improve its trade comparative advantage with respect to its neighbors.

This research is focused on the analysis specific to congestion and queuing patterns at the abovementioned ports, specifically on the discharge of agricultural grain product bulk carriers. Such vessels are handled under specific operational conditions and berthing patterns at those ports, creating a unique scheme which is worth analyzing. The research is based on a model simulating different scenarios for each port, based on real cargo volume and vessel arrival data for the year 2008. The simulations allow understanding the operational constraints each port has at berth. Furthermore, an M/M/2 queuing model is used to test the scenarios in order to identify any problematic and reinforce the findings obtained from the operational analysis results. The study demonstrates that congestion is in fact a problem at some of the ports and that the most critical conditions occur when peaks in cargo volume are present. Such seasonal peaks in volume cannot be handled appropriately by some of the terminals, deepening the congestion situation further by increasing queue lengths and queuing times.

On a final stage, a short term solution designed to reduce the impact of queues on ports and vessels is presented and tested. The solution in mention is based on the usage of barge convoys which are sent and positioned alongside the vessels queueing. Such maneuver is to be used to discharge partial lots of cargo on a ship-to-barge operation. By applying such alternative, queueing vessels are allowed to reduce time at port; therefore improving the flow of vessels in and out of the ports and reducing vessel delay times at port.

Relationship between Thesis Objectives and Report Structure									
Thesis Objectives	**Ch. 1**	**Ch. 2**	**Ch. 3**	**Ch. 4**	**Ch. 5**	**Ch. 6**	**Ch. 7**	**Ch. 8**	**Ch. 9**
To construct a simulation model based on a real life case which allows to test the queueing model		o		•	•	•	•	•	
To be able to link the practical approach to the theoretical approach from the MM2 queueing model	•	o	•	o	•	•	•	•	•
To identify a congestion problem in the selected locations		•			•	•	•	•	•
To understand and explain the MM2 queueing model		o		•	o	•	•	•	•
To identify queueing patterns and conditions at each location	o	o	•			•	•	•	•
To propose a solution to the findings obtained in the queueing model	•				•		•	•	•
To be able to test the solution and verify its positive contribution to the situation		o	•		o	•	•	•	•

• = strong relationship; o = weak relationship

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Chapter 1 Introduction

The natural tendency of the world economy aims to towards increased economic growth. Unprecedented economic expansion experienced across the globe during the last five years, inevitably has a direct effect on trade volumes within countries. Better economic conditions in a specific society result in higher acquisitive power which in turn results in higher demand and consumption of goods and services. In addition, a trade liberalization wave has emerged for the last decade across the globe, creating new trade flows which were inexistent in the past. That condition gives a basis for countries to be incentivized to increase trade volumes not only with neighbors, but also with nations all around the globe. with which trade had never been possible due to trade barriers. Those conditions demand more efficient and more flexible supply chain processes which are able to cope with the challenges economic and trade growth carry.

The high levels of perfection and seamlessness demanded by the supply chain creates scenarios of high stress on the infrastructure available to transport and handle such goods from origin to destination. No supply chain is exempt of such stress condition. For such reason, the pressure applies to the supply and delivery of raw materials and commodities and intermediate goods and finished goods as well. The circumstances arising from the growth scenario described have reshaped the transport, port, terminal and storage business and operational models. Such industries, which serve as connecting legs and nodes of a supply chain are affected by growth in trade volumes and have to adapt as quickly as possible to that circumstance. Any particular group within those industries that does not keep up with the demands, by increasing capacity or flexibilizing its modus operandi to suit the ever growing trade market demands, will be doomed to be highly underproductive agents destined to disappear in the mid or long run.

Considering the statement above, the needs required by an optimally operating supply chain, increase the challenge ports and terminals have on reducing bottlenecks at their stage of the process. The ship to shore or shore to ship transfer of goods must have a minimal impact on the total time any product takes from origin to final destination. However, bearing in mind the fast pace at which trade volume growth has increased, infrastructure available in many areas of the globe does not have the capacity to grow accordingly. That circumstance translates into the fact that infrastructure cannot keep up the pace to cope up with the requirements, trade demands for seamless origin – destination transfer processes. The reason to this lag on expansion is mainly due to time, economic and operational constraints.

The scenario described above is even more acute in developing countries, which have experienced a trade volume growth average of 7.28% per annum between the years of 1981 and 2007 (UNCTAD, 2008). The specific case of Colombia, country which will serve as setting for the analysis of this research is a nation which was not exempt to such circumstances. For this reason, Colombia experienced severe constraints in various steps of the import and export supply chain for a wide diversity of its industries. The country's trade volume growth has averaged an increase in imports of 20.6% per annum for the period comprehended between the years of 1994 and 2008. On the other hand, it has experience an average volume increase of exports during the same time period of 25.5% per annum (Mincomercio, 2008). Although efforts from the public and private sectors have been made to provide an efficient supply chain, it is still not enough. As a result, bottlenecks all across the supply chains are inevitably present. See Diagram 1 & Diagram 2 identifying geographical location of city ports researched in this thesis.

The particular case of the Colombian sea ports experienced seasons of severe congestion. That circumstance, translated into high economic losses caused by demurrage charges due to vessel owners, reduced berth productivity and vessel turnaround time and the impact on other agents involved further down in the supply chain. The most critical consequence of congestion is the negative impact on the competitiveness and value added the country can provide to specific industries and markets.

This research will be focused on studying the impact of port and berth congestion at terminals dedicated to handling the discharge of agricultural grains in bulk at the three major Colombian Caribbean coast ports of Santa Marta, Barranquilla and Cartagena during the year 2008. A complete analysis of vessel arrivals, berthing dynamics, time losses and queueing vessel scenarios will be conducted. Such study will be guided by the application and analysis of a selected basic queueing model. The data results from the model will serve as complementary information to understand the berth congestion situation at each one of the abovementioned ports.

Diagram 1: Map of the America's: Focus on Colombia

Source: Google – Map Data © 2009 Europa Technologies

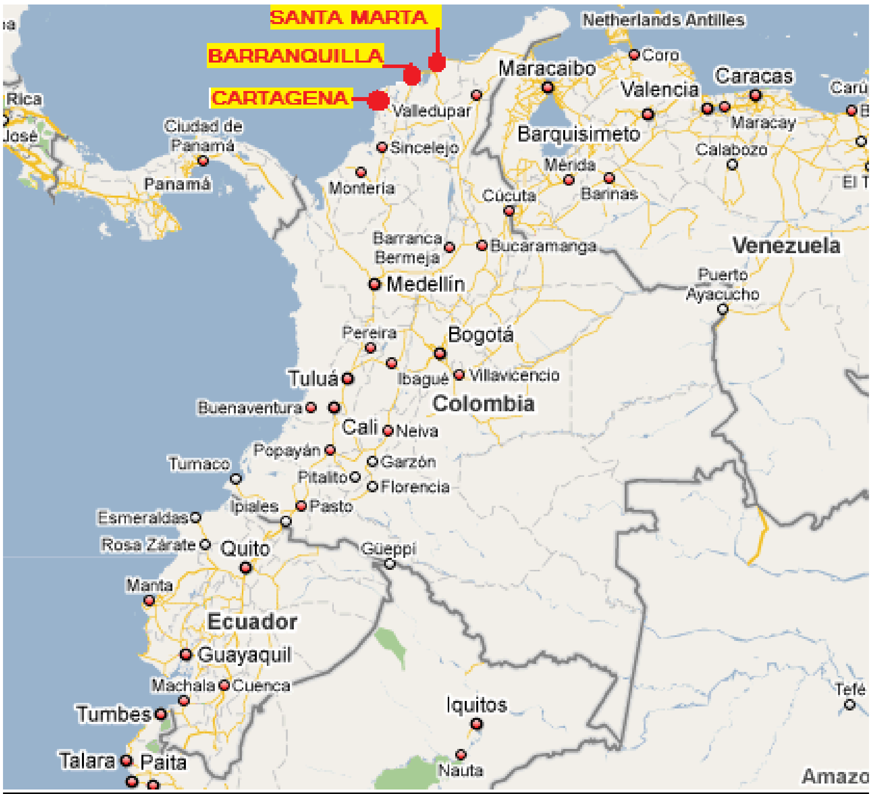

Diagram 2: Map of Colombia:
Highlight of the cities of Santa Marta, Barranquilla and Cartagena

**Source: Google – Map Data © 2009 Europa Technologies*

1.1. Research motivation

The interest in this particular field of research is to study the specific cases in which congestion and queuing events occurred at the three abovementioned Colombian ports during the year 2008. Furthermore, it intends to evaluate the consequences such situations carried to the overall terminal operations, vessel arrivals and berthing flows from a time loss and berth congestion perspective. Finally, it is intended to be able to propose a solution which supports the terminals operation in situations in which such port congestion situations occur.

The result of chronic congestion at a port or at any point in the distribution channel of products, translates into an increased lead time [1] for goods. It is considered to be a condition that acts on any goods exchange activity as any conventional trade barrier does such as a duty or a quota. Nordås, Pinali and Grosso (2006) provide us with an example of how excessive lead time in the delivery of goods affects trade opportunities in the United States. “Time to market has two distinct effects on trade: first, it determines whether or not a manufacturer

[1] Lead time is the amount of time between the placement of an order and the receipts of the goods ordered. It depends on the nature of the product e.g. whether it is made to order or if it is a “from the shelf” product (Nordås, Enrico, & Grosso, 2006).

will enter a particular foreign market. This is a variable with two possible outcomes - enter or not enter. Second, time affects the volume of trade once a market entry is made. David Hummels (2001) made the distinction between these two effects in a careful and detailed study of U.S. imports. He found that an increase in shipping time of one day reduces the probability that a country will export manufactures to USA by 1.5%. Presumably, delays due to other causes as administrative procedures related to exporting or importing, delays on the domestic leg of the transport route - including waiting time for shipment - and delays related to testing and certification of goods will have the same effect on the probability of exporting to a particular market as has shipping time" (Nordås, Enrico, & Grosso, 2006).

The personal motivation from the author of this research in the topic stems out of his own observations from his professional experience in a grain trading company in Colombia. The frequent occurrence of congestion events during his duty in the operations department of the organization raised his attention towards that specific problematic. The authors concerns stand on the direct consequences congestion has on competitiveness and trade opportunities. In view of the practical experience and his academic background, the author has considered this an interesting topic to review, analyze and understand in more depth through this research exercise.

1.2. Problem definition

"Once, port congestion was a fact of life and shipping people were wearily resigned to long waits for berths and delays for every conceivable reason. People kept huge stocks of goods and raw materials to guard against delay. But shipping today is far more of a precision industry and is thus more vulnerable to delays from port congestion. A containership, which fails to get alongside because the berth is occupied, will miss the special train waiting for its boxes, and the goods which were anticipated "just in time" will be delayed. Which is why there is pressure on ports to invest more and have more reserve capacity to keep the ships moving and the cargo arriving on time. Congestion is simply too expensive to tolerate today (BIMCO, 2009)."

The above statement expressed by BIMCO defines the negative magnitude congestion can bring to the supply chain. Excessive traffic situations at ports create bottlenecks in the supply chain, which translate into delays of processes further down the line. The consequence of such delays can be depicted as creating a "bullwhip" effect, for wholesalers and retailers along the chain. "The *bullwhip* occurs when fluctuations in orders increase as they move up the supply chain from retailers to wholesalers to manufacturers to suppliers (Chopra & Meindl, 2001)."

To understand the sources of congestion in a given terminal, it is important to highlight that different types of congestion exist. Such types are described as follows. "The first type is *Occasional Congestion*, which occurs because of unpredictable reasons such as a sudden disruption of the infrastructure or peak traffic. The second type is the *Structural Congestion* which is of a perennial nature and stems out either from ill-adapted infrastructure, insufficient for the level of traffic within the physical and environmental constraints, or due to a lack of technical compatibility. Administrative procedures or handling problems are other causes of congestion. Places plagued by structural congestion are bottlenecks (CLECAT, 2006)".

Considering the above definitions, it is important to locate the Colombian ports situation accordingly. In a first level, the congestion episodes viewed in 2008 were deepened by peaks in incoming vessel traffic, generated by increased trade volumes (Naves Colombia S.A., 2009). The condition described above can be considered as a partial cause to the Colombian ports congestion problem, positioning them on the Occasional Congestion segment. Thus, from the perspective of the author of the present study, the most influential factor on congestion is based on structural issues. Such issues are based on a lack of infrastructure in terms of berths, discharging equipment, hinterland connections and on site storage capacity.

Cases of excessive congestion are extremely expensive for the supply chain overall. Particularly during 2008, congestion charges were higher than other years, not only for the higher amount of demurrage costs and vessel queuing cases, but because freight rates had increased dramatically. Since the freight segment of the agribulk business is hired on tramp bulkers under time charters and voyage charters, demurrage and despatch rates fluctuate proportionally one-to-one with freight rates. In view of this, interest exists amongst port authorities and port users to reduce the probability of queuing events. In view of the large amounts of investment required plus the physical capacity constraints and time needed to obtain new equipment and infrastructure installed and operating, supply chain agents are seeking for flexible alternatives that can aid reduce bottlenecks and improve the bulk vessel discharging process during congestion seasons.

On an initial stage, this research analyzes the different berthing patterns and conditions for each port. Depending on capacity and infrastructure, each port operates according to its own needs. On a second stage, the real ports’ congestion situation is reviewed under an operational and theoretical standpoint.

The analysis is aimed towards the proposition of a simple solution to apply in cases of congestion under such circumstances. The proposition will be tested on the same scenarios examined in the first stage with the intention of viewing the benefits of such on the basic scenarios presented.

The solution proposed is based on the idea of discharging a percentage of the cargo on board vessel queuing at anchorage onto barges positioned alongside the ships. The purpose of such maneuver is to gain make up for lost time during the queuing episode and therefore, reducing the berthing time and vessel turnaround, once it is finally sailed into the harbor for discharge. The proposal should be achieved by using small self equipped barges, in a vessel-to-barge operation. Here, the latter will approach the vessels at anchorage in order to load part of the vessels bulk cargo into its holds, for immediate delivery to the port area. This solution will be approached from a queuing theory perspective therefore any specific technical requirements will not be described or investigated in this research.

Congestion at ports generates a major impact all across the supply chain. Bottlenecks in the vessel arrival and discharge process alter the different parties involved in the operations. The result of such situations is the generation of high stress levels on the supply chain. Being able to identify flaws in the pipeline flow of goods, helps to reduce costs, improve competitiveness and facilitate trade.

1.3. Theoretical application

Waiting line analysis, also known as queueing theory is known to be a branch of applied probability theory (Willig, 1999). Under such discipline several models have been developed, applicable to different population arrival patterns into systems with different service centers and servers. The author considers that approach as a valid theoretical application for the case studied in his research. Detailed application of the queueing model selected will be described in detail in the Chapter number four.

1.4. *Research question*

The different considerations described in the first sections of this research have allowed the author of this thesis to formulate a Research Question aiming to understand the full scope of specific delay events in the ports used as samples in this analysis:

Does flexibilizing the supply chain, or increasing discharge capacity at selected bulk terminals, significantly reduce total queueing time and total queueing events caused by bottlenecks and congestion at discharge?

1.5. Thesis structure

This thesis has been divided into nine chapters. Chapter 1 provides general introductory information on the research background. In this chapter, the general information is briefly linked to the theoretical application selected as well as to the research question formulated by the author.

Chapter 2 provides specific details on the location and market the model constructed is being applied at. It serves as a basic understanding on the rationale to the *modus operandi* of the model. It also introduces the reader to general facts on the geographical location of the scenarios selected for the research.

Chapter 3 describes in detail the berthing dynamics of each of the ports studied. It allows the reader to have an understanding of how vessel berthing operations take place at each port from a practical point of view.

Chapter 4 explains the general aspects of queuing dynamics. It is a summary of how various queuing models are conceived and describes the theory behind the selected queueing model for this research. Finally, the thesis literature review is presented in this chapter.

Chapter 5 is a description of how the data used for the analysis was collected and how it was configured into a test model which resembles the real life berthing dynamics at the ports being evaluated. It describes how the data has been organized into different simulated scenarios for each port and illustrate how the outcomes of the application of the test model are organized so that they can be used in the selected queuing model.

Chapter 6 is a detailed description of the use of each of the variables applied in the test model. It allows the readers to understand how the test model has been set up in accordance with the real life berthing procedures of the ports.

Chapter 7 explains the results obtained from the queuing model and the test model. It serves to identify the different queueing events, times and delays for each scenario created. It also allows to understand the reasons and cases in which queueing is more likely to happen under specific circumstances.

Chapter 8 describes the results obtained from the application of a barge network solution to the different queuing scenarios discussed in Chapter 7. The information contained in this chapter reveals the benefits of applying an alternative to improve the berthing dynamics at the ports.

Chapter 9 provides the conclusions and remarks of the research and the suggested solution. It also contains any particular suggestions for any research interested in continuing the research in the future.

Chapter 2 Colombian agricultural bulk product supply chain

The ports of Santa Marta, Barranquilla and Cartagena “Muelles El Bosque” Terminal, located on the Colombian Caribbean coast, are multi-purpose facilities, which handle containerized, general and bulk cargo. Each one of them is independent from the other two and handles its operations and volumes according to their own needs and strategy. Each location counts with its own operational teams and interact with private independent stevedore companies that take charge of vessel loading and unloading operations.

At each of the three abovementioned ports, cargo segments have experienced congestion issues during the years 2007 and 2008. Cargo handling and storage completely differ from one segment to another. Specifically, the handling of dry bulk agricultural products requires specialized equipment, storage facilities and operational strategies. This research will focus exclusively on the general conditions pertaining vessel arrival and discharge operations at ports and the waterside – landside cargo transfer scenario for **handymax type bulk carrier vessels**.

Specifically, the Colombian agricultural bulk (*agribulk)* product import business is handled in handymax bulk carriers, which have been selected by the national importers and traders as the optimal size vessel which fits the local market demand. Handymax vessels are able of carrying up to 56,000 mt. of product on board (Wijnolst, 2009). The vessels in mention are useful in developing country’s ports since they equipped with own gear on board. It is a characteristic that can be counted as an advantage, since many ports from developing countries have limited infrastructure for discharging products. In turn, the cargo discharge rate is improved by using the vessels gear as well.

2.1 Grains imports market and volumes

The Colombian grains market is focused on purchasing agricultural commodities destined to the production of animal feed, or on the other hand, for milling purposes for the production of different varieties of flour. The market mainly demands yellow corn, different wheat varieties, soybeans, soybean meal, sorghum and other sub products. The products are loaded on board the vessels under two different schemes. The first scheme is one in which a vessel is fully loaded with one single product on board. The product can either be discharged at one port, or it can also be discharged at two or more ports. The second scheme is one in which different products are loaded inside the different cargo holds of the vessel. In some cases, even more than one bulk product is loaded in one single hold; for such modality, plywood separations are installed between the two products to avoid product mixing. Vessels loaded with one single product usually have a faster discharge rate than dual product vessels. The reason being is that regardless of the unloading plan prepared by the master, the same product will be discharged from any hold. Such scheme avoids time wasting due to discharge stoppages at specific holds for stability reasons.

Products are originated mainly in the United States Gulf Coast, United States Atlantic Coast, Canadian West Coast, Argentina, Paraguay and Brazil. Due to the proximity between the three ports it is common to discharge part of the cargo at a first port and the remainder at a second port. Doing so allows for full handymax vessels to be loaded, taking advantage of economies of scale large ships are able to obtain (See Table 1).[2]

Table 1: Intra-Port Distance

Route	Distance in Kms.	Distance in Nautical Miles	Sailing Time in hrs (aprox.)
CARTAGENA - BARRANQUILLA	185.2	100	7
CARTAGENA - SANTA MARTA	227.8	123	12
BARRANQUILLA - SANTA MARTA	92.6	50	6

Source: Port World, 2009

Each of the ports has specialized equipment to aid the discharge of bulk vessels such as pneumatic suction machines, or shore cranes with specialized grabs, each with lift capacity between 80 and 120 metric tons (O.S.I. Trademar, 2002). The equipment is either dedicated to a specific berth(s) or it can be movable equipment which can be approached to any pier position as it is done with shore cranes. Furthermore, for every single case, the gears on board the vessel are used in the discharge process in order to increase berth productivity and vessel turnaround time.

Colombian ports have not been an exception to congestion during the year 2008 and all of the parties described above have been affected. In view of the increase in imports volumes of agribulk cargo into the country in 2008, the ports of Santa Marta, Barranquilla and Cartagena experienced different congestion events. The congestion has translated into elevated economic losses and time wasting in the form of queues, bottlenecks, supply chain interruptions and demurrage charges. The difference in delay scenarios presented between the three ports not only due to cargo volume differentials and physical constraints but also due to berth productivity performance, and operational strategy applied. Furthermore, each port serves different regions in the Colombian hinterlands which demand different products and count with different road infrastructure conditions.

The port with the highest congestion cases during the year 2008, corresponding to handymax agribulk import vessels is Barranquilla[3]. The main reason for such congestion cases has been the high growth levels of imports volumes viewed in 2008 which can be attributable to many factors. Second of all, congestion has been caused due to draught restrictions at the port access channel, since the port is located on the Magdalena river mouth, 21 kilometers up river from the Caribbean Sea. The average access channel draught however is 9.14 meters (SPRB, 2002).

The Port of Santa Marta has experienced congestion due to volume increases as well; condition which will be reviewed in the data analysis chapter. The increased demand for animal feed has been part of the reason for the agribulk imports through this port. Its geographical proximity to many production facilities of the country makes of this port, the natural receiving location for much of the corn, soybeans,

[3] Cargo volumes for the ports of Santa Marta, Barranquilla and Cartagena can be viewed in the data analysis chapter of this research.

soybean meal and sub-products dedicated to the animal feed. It is important to say that the poultry industry in mention, serves not only the Colombian market, but the Venezuelan market as well. [4] Nevertheless, it is important to keep in mind that the port of Santa Marta has a year round free 40 feet draught access channel, which imposes absolutely no problem to vessel operations, regardless of tides (SPSM, 2000).

Table 2: Total cargo import volumes for agribulk products per port for the period comprehended between 2006 and 2008

PORT	YEAR	TONS[5]	INCREASE WRT PREVIOUS YEAR
SANTA MARTA	2006	1,088,869.73	N/A
BARRANQUILLA	2006	1,338,582.00	N/A
CARTAGENA	2006	390,305.16	N/A
TOTAL FOR 2006		**2,817,756.88**	**N/A**

PORT	YEAR	TONS	INCREASE WRT PREVIOUS YEAR
SANTA MARTA	2007	1,180,417.86	8.41%
BARRANQUILLA	2007	1,471,570.60	9.94%
CARTAGENA	2007	347,581.98	-10.95%
TOTAL FOR 2007		**2,999,570.44**	**6.45%**

PORT	YEAR	TONS	INCREASE WRT PREVIOUS YEAR
SANTA MARTA	2008	1,452,419.03	23.04%
BARRANQUILLA	2008	1,512,890.64	2.81%
CARTAGENA	2008	438,891.37	26.27%
TOTAL FOR 2008		**3,404,201.04**	**13.49%**

** Source: Colombian Import Statistics Database: Naves S.A.*

The Port of Cartagena has several different terminals; however agribulk cargo is discharged exclusively at the "Muelles El Bosque" multi-purpose terminal.[6] This port handles much lesser agribulk volume than the other two analyzed, mainly for its reduced storage capacity and relatively small local market. However, it has experienced interesting volume growth levels in the last few years[7]. Congestion in this port has been minimal in this particular segment; however, room for improvement is always possible (See table 2).

[4] Remark based on observations collected by the author of this document during his 2.5 years experience in the market being analyzed in this study.

[5] Corresponds to measurements in Metric Tons

[6] The terminal of Cartagena Muelles El Bosque will be identified as *"Port of Cartagena (MEB)"* in this research.

[7] Cargo volumes for the ports of Santa Marta, Barranquilla and Cartagena can be viewed in the data analysis chapter of this research.

2.2 Effects of congestion on the supply chain

In order to understand the effect of bottlenecks on the Colombian agribulk imports segment, it is important to understand how the supply chain is configured (See Diagram 3). On one end of the chain, sits the seller of the grains previously identified. This individual is usually abroad. On the other end of the chain is the producer of the animal feed or the flour which uses the products as raw material for its process. Such companies are usually flour mills, animal feed producers or re-sellers. The cargo flows from origin to destination passing a number of different nodes.

The first part of the chain starts at the grain elevator where the product is stored. At such location, the product is loaded on a vessel chartered to transport the grain into a selected Colombian port. Upon arrival to port of destination, the grain is discharged and it is either stored at the local port silos or it is transported via trucks to the buyers mill, factory or storage facility. [8]

The disruption of the flow or the presence of bottlenecks at any level has implications all throughout the chain. Nevertheless, the interruption of the process at the port, can affect more groups than any other node in the chain. The reason is the fact that three other groups are directly affected by such disruption, the vessel, the silos and the land transportation. Such parties directly affected do not count with enough response time to adapt to the last minute changes or problems that can occur at the port. On any other step of the chain, only either one or two parties are directly affected by any change or delay. From this perspective, it is important to understand the extent of the presence of bottlenecks on each one of the parties involved in the chain, from an economic perspective as well as from an operations standpoint.

Congestion impact on vessel owners

The first group negatively affected are vessel owners which cannot turnaround their equipment as fast as desired. Given that circumstance, the total number of sailings per year is reduced, directly affecting their profit records. On the other hand, the longer the time owners are bound to a contract, the less opportunities they will have to be out in the markets, taking advantage of any beneficial freight rate change, or being able to charter the vessels to a higher paying bidder. In other words, the assets are captured longer than desired under a specific contract.

Congestion impact on importers

The second group negatively affected is the cargo importer or consignee. That particular party receives strong pressure from two perspectives. On one end, it will generally have to pay for demurrage charges at discharge port for any overtime generated by the situation. As the handymax bulk vessel freight market is highly volatile, during high congestion periods freight rates tend to increase as well, raising the transport cost component. On the other hand, demurrage charges on charters increase proportionally with respect to freight rates. For this reason, during high

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[8] See Diagram 1 for diagram on agricultural bulk goods supply chain.

demand and high congestion periods, demurrage charges increase as well. The problem the importer encounters is that increased transport costs caused by congestion are not easily transferred to the final consumer via pricing, forcing the importer to absorb the additional costs.

Congestion impact on ports

A third party affected is the port itself. Although berth usage during high vessel traffic seasons is elevated and economic benefits are present due to high berth demand levels, extreme congestion is a disincentive for other shippers or vessel owners to use that particular terminal in the future. From the vessel owners' perspective, they will compensate any possible economic losses incurred in for calling a port with high probability of delays by increasing the freight rates to that particular port. From the perspective of shippers, they will intend to avoid bottlenecks by using alternate ports or alternate transportation means. Such a situation decreases the attractiveness and the competitively of the port forcing it to charge less for its services in order to stay in line with its competitors. Ports must always be keen on vessel turnaround times, in order to use that rate as an attractive condition on their favor.

Congestion impacts on warehouses and storage facilities

A fourth party which is affected by port congestion is the segment of port storage facilities and warehouses. Excessive imports volumes will imply storage under capacity. When storage is not able to cope with incoming cargo needs, a spillover effect is generated, same which is immediately reflected at the berth. In such case cargo has to be transferred out of the port area directly to importers facilities; generating truck or rail traffic congestion within the port as well as at the gate.[9]

Congestion impact on trucks

The fifth group affected by congestion events at ports is truckers.[10] Such segment faces similar circumstances as the ship owners do, but from the land side perspective. Sending trucks to congested ports will imply having the vehicle caught up queuing longer than desired, therefore applying a factor of low productivity to the asset. Once again, vehicle turnaround and utilization are negatively impacted by the situation. In order to be feasible for a trucker to pick up or deliver cargo from or to such ports implies increasing his freight rates in order to cover for increased costs.

Congestion impact on importers, wholesalers and retailers

A sixth groups' operation which is negatively impacted by congestion is the importers, wholesalers and retailers cluster. In situations in which the ports become a bottleneck on the import leg, stock levels are altered and original inventory management plans are seriously affected. The consequence of this circumstance to

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[9] Observation based on the personal experience from the author of this research.

[10] Railroads are not considered in this remark. The Colombian railroad industry does not serve the industrial segment being analyzed in this research.

the abovementioned groups is the need they have to increase their inventory levels, as a preventive measure in order to avoid any stock outs, caused by the slow inflow of product to its facility. Such a decision implies additional costs in terms of inventory depreciation, risk and warehouse usage.

When all of the cost increases above are summed together, a general loss of welfare is generated on society. The basis to this is the excessive waste of time created but more important, the excess costs incurred in by every single player in the chain. As players intend to pass on any cost increases further down the chain, the big loser is the final consumer who will be affected by increased inflation and a general loss of competitiveness in his region.

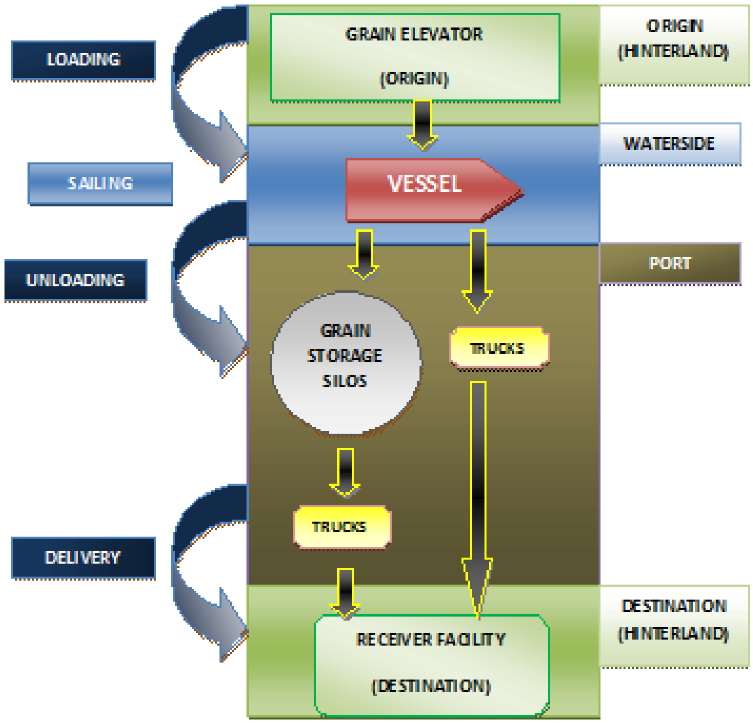

Diagram 3: Agricultural bulk supply chain diagram

**Supply chain flowchart. Elaboration of the Author.*

Summarizing the above, the supply chain is seriously affected by any bottlenecks caused at the port, which is the primary waterside-landside transfer stage of the flow of products from origin to destination. The effect of such bottleneck, spills over not only to the waterside parties, but also to the port waterside parties and furthermore, to the hinterland parties. Any effort or reduce such impact, by improving port operations or by flexibilizing the supply chain are to be welcome by all the interest groups involved.

Chapter 3 Port operations

Berth assignment decisions vary from one port to another, depending on infrastructure available for the corresponding operation. The ideal case occurs when a vessel announces its arrival at the ports Pilot Station and it is immediately ordered to proceed to the berth that best suits its discharging needs in terms of space, infrastructure and most of all, turnaround time. This is the approach Port Authorities and terminals give to berth assignment decisions with the intention of offering their clients the first best option available. Nevertheless, circumstances are not always optimal and alternatives have to be sought to assure the most rapid vessel turnaround times attainable under the existing conditions. In cases when the optimality scenario is not possible, the flows of vessels in and out of the port vary creating queues and delays to newly arriving ships.

Each one of the three ports being analyzed in this research has its own berth constraints and operational conditions. This characteristic implies that port situations are heavily affected by such factors, resulting in different vessel turnaround times and vessel management at berth. Nevertheless, they do follow one basic principle in terms of service priority upon arrival. All of the three ports in mention without exception, berth assignment and berth priority decisions are based on a first in first out (FIFO) queueing discipline[11].

At the ports of Santa Marta, Barranquilla and Cartagena only few berths are strictly assigned to agribulk vessel discharge due to capacity restrictions. Whenever such berth or berths are in use, any ship arriving after the vessel(s) at berth, will be either assigned a secondary berth whenever available or otherwise, will queue at anchorage area until space is freed up. Although other berth positions are available in each one of the ports, priority for berth assignment other than those specifically dedicated to agribulk is given to liner ships, RO-RO car carriers, or even fruit product vessels which have time limitation for delivery due to tight schedules or the perishable nature of cargo respectively.[12]

The vessels referenced in this study are not liner vessels but instead they are “tramp” vessels. Ernest C. Fayle (1932) describes a tramp vessel as a “seeker” or a ‘general’ trader as one ‘…in which can be hired as a whole, by the voyage or the month to load such cargo and to carry it between such ports as the charterer may require…’. The above description of tramp vessels indicates that these ships have

[11] Discipline of a queueing system means the rule that a server uses to choose the next customer from the queue (if any) when the server completes the service of the current customer. Commonly used queue disciplines are:

FIFO: Customers are served on a first-in first-out basis.

LIFO: Customers are served in al last-in first-out basis.

Priority: Customers are served in order of their importance on the basis of their service requirements (Browne, 2006).

[12] Information provided by the author of this research based on personal experience.

no fixed itinerary or cargo. Such condition is an important element terminals must not forget to be able to prepare for the arrival and unloading operations of tramp ships. The most distinctive characteristic tramp vessels business has is the lack of defined route and port of call schedule. This consideration provides ports and terminals with an important challenge to overcome, as it is barely impossible to control vessel arrival patterns into their facility. The challenge is based mostly on providing the fastest service at berth to each vessel, whenever a number of ships arrivals higher than average occurs. Furthermore, terminals have to combine the unpredictability condition of tramp carriers with the fixed sailing schedule of liners into their restricted quay wall space. Many alternatives are possible in order to approach the problem. In the following pages, a description of how the ports of Santa Marta, Barranquilla and Cartagena do so is presented.

3.1 Berth assignment dynamics at the Port of Santa Marta

The port of Santa Marta has seven berthing positions suited for different types of vessels. Specifically, berth number four is exclusively dedicated to the discharge of agribulk products. Berth number four is equipped with specialized suction equipment with a direct conveyor line to storage silos (SPSM, 2009). Whenever the dedicated berth is busy and a second agribulk vessel calls the port, a second or alternate discharging berth can be assigned. Nevertheless the second position assigned will not be able to provide the discharge rates the dedicated facility offers. The main reason for this situation is the lack of specialized equipment at the alternate pier such as direct berth – silo conveyors required for this type of operation.

Berth number four can achieve discharge rates of about 6,500 metric tons (mt.) per day SHINC[13] for Handymax bulk vessels, under perfect conditions[14]. However, port users consider discharge rate of 5,500 metric tons per day SHINC as a rule of thumb for Handymax bulk carrier discharge (Cuevas, 2009). In this research, this position will be identified as “Berth A”.

The alternate berth for discharging the vessels being considered in this study is position number three. This berth is not an agribulk product discharge dedicated pier; therefore, vessels moored there will achieve a lesser discharge rate than that of Berth A. Generally, discharge at this position is done with on board the vessel gear and at times it is aided by a movable shore crane provided by the port. For this reason, as a rule of thumb, the general discharge average is generally accepted to be about 4,500 mt. SHINC (Cuevas, 2009). In this research, this position will be described as “Berth B”. The specific application of average discharge rates to this research will be discussed in detail in Chapter 3.

The operation and berth assignment at this port is determined by a FIFO discipline. Once a vessel arrives at the pilot station and tenders the corresponding N.O.R. (Notice of Readiness) to the Port Authority, the latter will assign a berth accordingly. Different sub-scenarios at the berth location can happen at this specific moment, same which are described in the following pages.

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[13] Acronym meaning: Sunday’s and Holiday’s Included (SHINC).

[14] Perfect conditions imply that the discharge process is not stopped or delayed by rain or heavy wind, or disruptions on the landside operation or gear breakdown.

The first scenario is considered to be the ideal situation. It occurs when a vessel arrives at the pilots' station and Berth A is free for immediate use. Such condition implies that the vessel will be sailed to the port and discharge operations will commence instantaneously. In this case, there is no need for the vessel to queue or to wait for any berth preparation activity. Therefore, such scenario must result in the highest discharge rate possible for agribulk vessel discharge operations at the Port of Santa Marta. The abovementioned berthing dynamic is depicted in Diagram 5.

Diagram 4: Key table for berthing dynamics diagrams

1 *- Representation of first vessel arriving at the port. (System user number one)*

2 *- Representation of second vessel arriving at the port. (System user number two)*

Q *- Representation of any vessel quequeing at the pilot station. (System user queueing)*

ps *- Representation of Ports Pilot Station. (Point of entry to the system).*

A B *- Representation of Berths A and B at each port. (System servers and system exit points)*

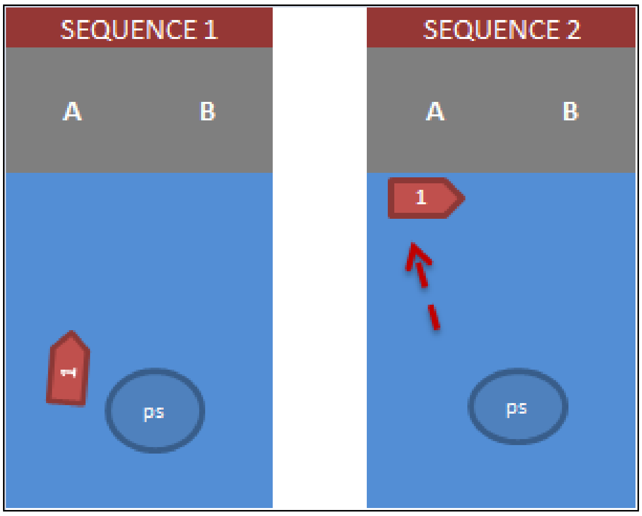

Diagram 5: Port of Santa Marta, first scenario berthing dynamics

Vessel 1 directed immediately to empty Berth A. Elaboration of the Author.

A second possible scenario occurs when Berth A is being used by a vessel discharging product(s), upon the arrival of another agribulk ship at the ports' pilot station. If at the time the second vessel arrives, berth B is not in use, the Port

Authority will direct the second vessel there in order to commence immediate discharge. As mentioned above, Berth B has a slower discharge rate than Berth A therefore, being positioned at this location is not the ideal scenario since maximized discharge rates for the port in mention cannot be achieved. The abovementioned berthing dynamic is depicted in Diagram 6.

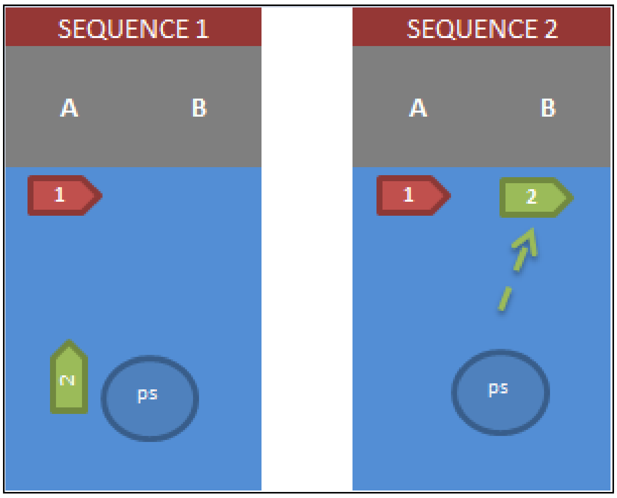

Diagram 6: Port of Santa Marta, second scenario berthing dynamics

Vessel 2 immediately directed to Berth 2. Elaboration of the Author.

Whenever a vessel is located at Berth B two possible sub-scenarios arise. In the first case, if the vessel located at Berth A ends its discharging activity and leaves the port before the vessel located at Berth B, the latter will be *shifted* to Berth A, in order to be able to increase the discharge rate. Although the *shifting* maneuver implies some time waste, it is a reasonable decision to take in order to achieve a higher discharge rate for the remainder of the operation. In doing so the advantage of the rates attainable at Berth A is used in favor of the vessel.

Whenever a shifting operation is required, on average; the maneuver takes one full hour. Such a maneuver implies a stoppage of the operation at Berth B, the shifting of the vessel from A to B using tug boats, mooring and restarting the operation at Berth A. Although having the ability of shifting a vessel from a slow discharging position to a fast discharging one is an advantage, it is still not the optimal situation for a vessel calling the port of Santa Marta. The abovementioned berthing dynamic is depicted in Diagram 7.

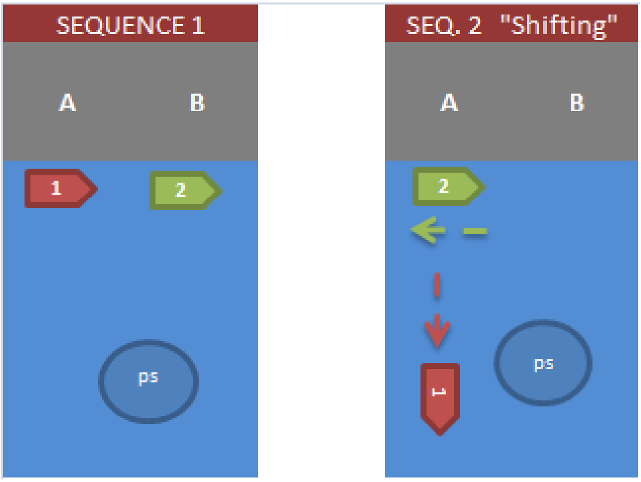

Diagram 7: Port of Santa Marta, second scenario- sub-scenario berthing dynamics

Vessel 1 departs after discharge ends & vessel 2 is shifted to Berth A from B to achieve faster discharge rates. Elaboration of the Author.

The second possible sub-scenario is one in which the vessel located in Berth B ends its discharging activity earlier than the vessel located in Berth A. In such case, the latter vessel will remain at Berth A in order to keep enjoying the fast discharge rates available. No shifting is required in such scenario. This particular case is not the ideal situation, since discharging rates achieved by the second vessel will not be optimal with respect to what the Port of Santa Marta can offer. Nevertheless is the second best situation at such facility. The abovementioned berthing dynamic is depicted in Diagram 8.

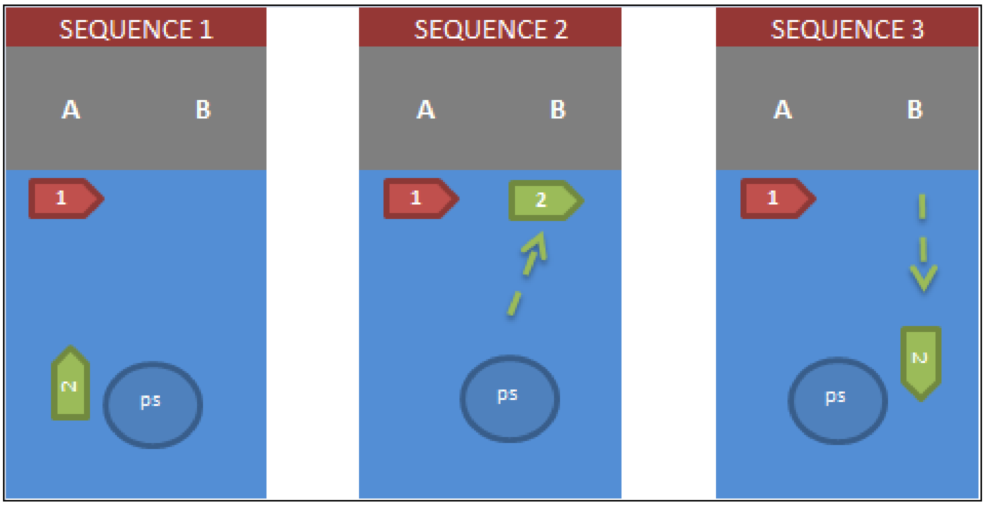

Diagram 8: Port of Santa Marta, second scenario- sub-scenario two berthing dynamics

Vessel 2 entering the slow discharge berth and departing earlier than vessel 1 located at the fast discharge berth. No shifting present in this scenario. Elaboration of the Author.

Considering the above circumstances, a third scenario is possible. It occurs whenever a Berths A and B are busy and a third vessel (*vessel Q*) arrives at the pilots station. In such circumstance vessel Q will have to wait at anchorage, until either berth is freed up. The situation described, translates into a queuing event. In view of the fact that the FIFO discipline is followed, vessel Q will inevitably be directed to Berth B to begin its discharge process at the slower turnaround berth.

Two berthing dynamics alternatives are possible in this given circumstance. The first case exists when vessel one is done discharging earlier than vessel two and, therefore, the latter is shifted to Berth A upon the firsts' departure. Correspondingly, vessel Q is taken in to Berth B for unloading.

The second alternative is the one in which vessel two is done discharging earlier than vessel one and empties Berth B. At that precise moment, vessel one will continue discharging at Berth A. In such event, vessel Q is directed to Berth B as well. Berthing dynamics for both alternatives mentioned are depicted in Diagram 9.

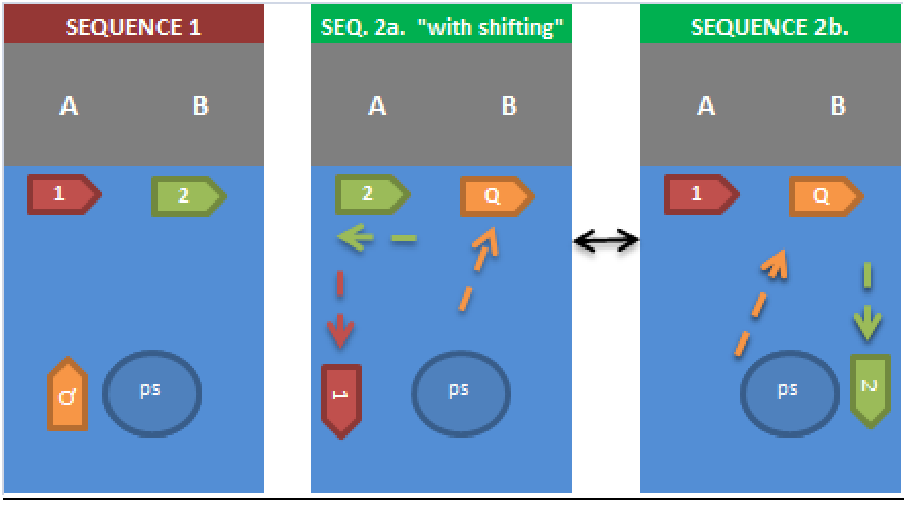

Diagram 9: Port of Santa Marta, third scenario sub-scenarios one and two berthing dynamics

Vessel Q arriving the scene and entering the slow discharging berth. Sequence with shifting for vessel two to Berth B and sequence with vessel two departing earlier than vessel one. Elaboration of the Author.

In the given case more than one vessel queues at the anchorage, the same process is followed observing the FIFO discipline. The process is therefore, repeated on and on until the queue is served and so that the vessels at berth are turned around the fastest way possible. Arrival patterns and discharge quantity needs are completely random; therefore virtually no operation is the same as any other.

The above conditions have been included in the model and have been tested in order to identify with the highest confidence possible. It is also aimed to identify the impact of queuing events is and how the solution proposed in this thesis can be of a positive impact to the discharge operations. The understanding of the above operational scheme is a key to the understanding of the model proposed in this research.

3.2 Berth assignment dynamics at the Port of Barranquilla

The Port of Barranquilla has six berthing positions. Position number six is exclusively dedicated to the receipt of handymax bulk carriers and discharge of agribulk products, same which are the focus of this research. It is equipped with a mechanized conveyor system directly connected to two grain silos. The remaining five berths are multi-purpose positions, assigned to different types of vessels. In view of the physical proximity of berth five to the grain silos, it is used as an alternate or secondary berth used to discharge agribulk products. When berth number 5 is used, discharge rates are very similar to those achieved in the dedicated berth, due to the fact that equipment used in both positions is similar and the mechanized equipment connecting the silos can be easily extended to berth number five (SPRB, 2009). From now on, dedicated berth, number six, will be noted as Berth A; the secondary berth, number five, will be noted as Berth B.

Berth A at the Port of Barranquilla has some differences with respect to its equivalent at the Port of Santa Marta in terms of equipment, since it does not count with pneumatic suction but instead with shore cranes. The discharge operation is aided by the vessels' gear on top of the shore crane. Together, a maximum discharge rate of 6,000 metric tons per day SHINC in perfect conditions can be achieved. However, the general rule of thumb average discharge accepted rate is of 5,000 mt. per day SHINC (Cuevas, 2009).

Berth B at the Port of Barranquilla, although not considered a dedicated berth for agribulk products, can be easily adapted to discharge such. With the help of a shore crane identical to the one used in Berth A, and a direct connection to conveyors connecting the grain silos available, average discharge rates similar to the ones obtained in Berth A can be achieved (Cuevas, 2009). For the purpose of this research, discharge rates for Berth B to be of 5,000 mt. per day SHINC as will be assumed as well.

It is very important to note that no shifting is executed at this port. Although Berth A is the main position and Berth B is a secondary position, both berths can offer equal discharge rates for every vessel. For this reason, shifting is <u>not</u> required whenever a vessel is at berth B, in order to achieve a higher discharge rate. The only operational difference between the two ports consists on the fact that Berth B is shared with other vessel types, which have berthing priority over bulk vessels. This condition, implies a higher probability for Berth B to be busy when a vessel arrives, forcing such vessel to queue until either Berths A or B is emptied.

In terms of the operation and berth assignment, the Port of Barranquilla uses the FIFO discipline as well. In view of the berth allocation strategy and discharge rates offered several different scenarios are probable to occur at this port. Such scenarios will be described in the following pages.

The first scenario is one in which a vessel arrives and Berth A is ready for immediate use. As it is done in the Port of Santa Marta, the vessel is immediately directed to such berth to begin discharging operations. No queuing is present in this case (See Diagram 10).

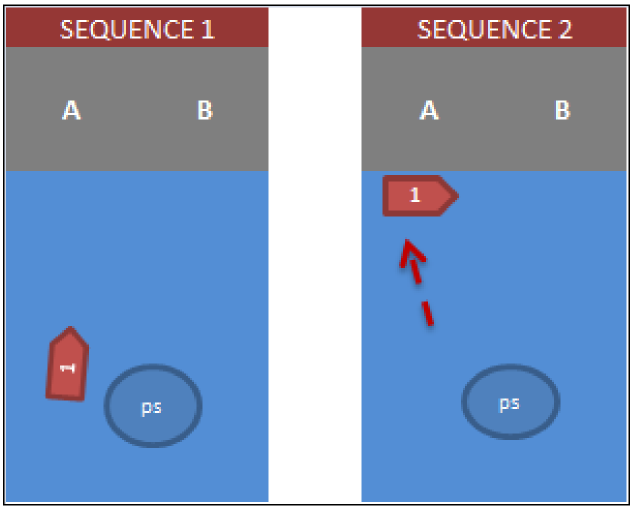

Diagram 10: Port of Barranquilla, first scenario berthing dynamics

Elaboration of the Author.

The second possible scenario occurs when Berth A is busy and a second ship arrives. In such situation, Berth B will be assigned and the ship will immediately be directed towards such position. As mentioned above, no shifting will be required if Berth A is freed before the vessel located at Berth B is done discharging (See Diagram 11).

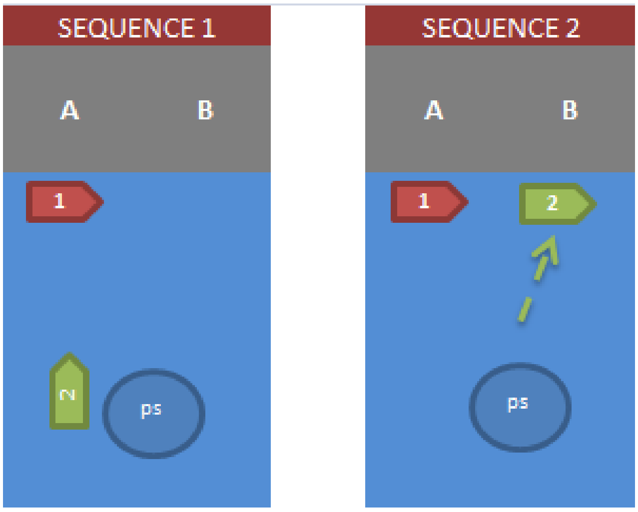

Diagram 11: Port of Barranquilla, second scenario berthing dynamics

Vessel two directed to empty Berth B. Elaboration of the Author.

The third possible scenario at the Port of Barranquilla occurs when both Berths A and B are busy and a third ship, vessel Q arrives. Such vessel will be forced to queue at anchorage until either Berth A or B are freed up. At this port, Vessel Q will have no preference for either Berth since discharge rates in both A and B are equal (See Diagram 12).

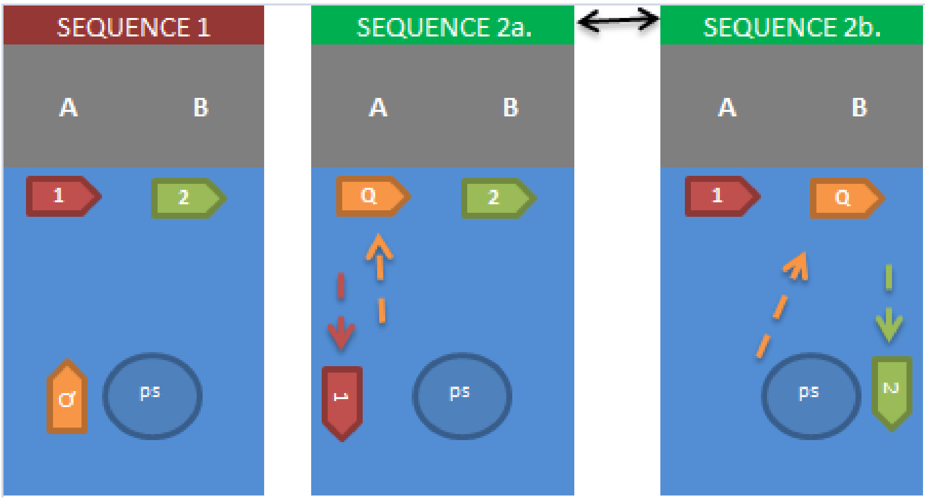

Diagram 12: Port of Barranquilla, third scenario berthing dynamics

Vessel Q queues until either Berth A (sequence 4a.) or Berth B (sequence 4b.) is empty.
Elaboration of the Author.

The conditions described above have been included in the model created for this research in order to identify any queuing situations generated during the year 2008 at the Port of Barranquilla. Such conditions will also be considered in the application of the solution proposed in this research. This research assumes no other possibilities for berth allocation at the port being analyzed.

3.3 Berth assignment at the port of Cartagena (MEB) terminal

The Port of Cartagena (MEB) counts with four berthing positions, from which position number four is exclusively dedicated to the discharge of agribulk products. Berth number three will be named Berth A from now on in this document. Such berth counts with a direct mechanized conveyor system used to transport the grain discharged from the vessels into the ports grain silos. The remaining three berthing positions are multi-purpose piers used to discharge containers, general cargo, liquid bulk and other bulk products (Terminal Maritimo Muelles El Bosque, 2000).

Discharge operations at both berths are handled by independent shore cranes same which are supported by on board vessel gear. In the case of Berth B, no mechanized conveyor system is available for direct product transport to silos. Such maneuver is handled using trucks, situation which reduces Berth B’s discharge rate capacity.

Whilst discharging in Berth A under perfect conditions, rates of up to 8,000 mt. day SHINC can be achieved. However, the industry recognizes averages of 6,500 mt. day SHINC as a rule of thumb. In turn, in the case of Berth B, discharge rates of 6,000 mt per day SHINC are achievable; however the generally accepted rule of thumb average taken by the industry is of 5,500 mt per day SHINC (Cuevas, 2009) (See Table 3).

Berth assignment at this port is based on FIFO discipline as it is done at the other ports being analyzed in this investigation. In view of the port conditions described above, several berth assignment possibilities can occur. The operation is identical to that of the Port of Santa Marta in which the main focus is to arrive to the fastest discharging berth position, in this case, Berth A. Therefore, any vessel initially berthed at position B, will expect to be shifted to position A once the latter is freed up. Since such berth is the position with the fastest discharging rates, being located there is the ideal situation for any vessel arriving at the Port of Cartagena (MEB).

As it occurs in the port of Santa Marta, liner vessels, produce and RO-RO vessels have priority at the port for any berth other than the grain dedicated berth (Berth A) in Cartagena as well. Therefore, it is common to observe cases in which the bulk carriers analyzed in this research are not given berthing priority whenever Berth B is assigned to them. Such condition has been taken into consideration in the model developed and its application in such will be fully described in the Model Application chapter of this research. All of the operational and requirements described for the Port of Santa Marta apply in the same manner to the Port of Cartagena (MEB) terminal.[15]

Table 3: Agribulk products discharge rates at ports

	MAXIMUM DISCHARGE RATE		AVERAGE DISCHARGE RATE	
	BERTH A	BERTH B	BERTH A	BERTH B
SANTA MARTA	6,500.00	5,500.00	5,500.00	4,500.00
BARRANQUILLA	5,500.00	5,500.00	5,000.00	5,000.00
CARTAGENA	8,000.00	6,000.00	6,000.00	5,500.00

Figures in metric tons per day SHINC
Source: Cuevas, 2009

[15] Berth dynamics are the same as in the Port of Santa Marta. For Port of Cartagena (MEB) port dynamics use Diagrams 3, 4, 5, 6 and 7 as reference.

Chapter 4 Queuing theory and queuing problem

G.F. Newell (1982) provides a very complete definition on queuing theory; same which reads as follows: “Queuing theory is concerned, generally, with the mathematical techniques for analyzing the flow of objects through some network. The network contains one or more locations at which there is some restriction on the times or frequencies at which the objects can pass. A conservation principle applies; the objects do not disappear or disintegrate. Any object which cannot immediately pass some restriction is stored in some real or fictitious reservoir until it can. As long as there are objects in the reservoir waiting to pass, the facility will pass them as rapidly as the restriction will permit”. The above definition is a very precise comprehension on the idea of queueing discipline and the objectives it is designed to accomplish.

The first person to study Queueing theory from an academic perspective was the Danish mathematician and engineer Mr. Agner Krarup Erlang (1878 – 1929). His studies on queueing events were based on the telephone system on his hometown of Lønborg. Back then, he analyzed the time people had to wait in order to be able to place a phone call outside of his village as all of the phone lines in the town were busy by other callers. He developed an equation to determine the probabilities of queuing, now known as Erlang’s formula. The idea behind his study was to understand in depth the phone call congestion process experienced at his hometown (Bhat, 2008).

After Erlang developed his research many others found an interest in the topic, expanding the discipline and finding other applications. Research on single queueing systems has extended to complex queueing networks were customers, after leaving a service center, enter a second and so on and so forth (Willig, 1999). The theory has advanced up to a point where sophisticated mathematical procedures become necessary. Thus the growth of queueing theory can be traced on two parallel tracks:

1. Using existing mathematical techniques or developing new ones for the analysis of the underlying processes; and
2. Incorporating various system characteristics to make the model closely represent the real world phenomenon (Bhat, 2008).

The real world simulated scenarios tested in this research resemble the second track described. The different variables of the scenarios created have been applied to the selected queuing model in order to represent a real case.

4.1 Theoretical framework on queueing theory: application to the research

"Queuing theory or waiting line analysis is classified as a branch of applied probability. It is practical in many different fields ranging from communications to computer systems, to machine plants to supply chain and transportation" (Willig, 1999). Queuing theory's usefulness relies on the basis that through its usage, the identification of queuing events from a probabilistic standpoint can be established. In turn, from the results, improvements to the service levels of a system in terms of design, existing infrastructure improvement and/or implementation of new infrastructure can be suggested and exercised.

"Research on this theory stems out of the study of three main variables which compose a system. The first variable is the, *service center*, which is the physical or virtual location where a specific service is provided."[16] "Such service is offered to a *population*; the second variable in the theory. The population enters the system, aims for a service location, gets the service performed by the service center and exits the system."[17] "The third variable or condition present in the queueing theory models is the *waiting line* or queue. A queue occurs when a service center has a limited capacity to serve only a certain number of customers in the system at a time. If a new customer arrives and the service center is completely busy, the customer queues until the service center become available."[18]

"Queuing theory aims to answer different questions regarding the system. Examples of such questions are the mean waiting time in the queue, the mean system response time (waiting time in the queue plus service time); mean utilization of the service facility, distribution of the number of customers in the queue, distribution of the number of customers in the system and so forth." [19]

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[16] Ibid. Page 3.

[17] Ibid. Page 3.

[18] Ibid. Page 3.

[19] Ibid. Page 5.

4.2 Structure and notation of queueing models

Queuing models have been organized under specific notations for model identifying purposes ease known as the Kendall Notation (Anderson, Sweeney, & Williams, 2003). The general notation used is in the form:

"**[A/B/s]**[20]

Where,

A *= Probability distribution of the arrivals*
B *= Probability distribution of the departures*
s *= Number of servers (channels)*

Amongst the probability distributions of arrivals and departures, special sub notations have been created as well:

M *= Designates a Poisson probability distribution for the arrivals or an exponential probability distribution for service times.*[21]
D = *Deterministic distribution – all values are constant*
G *= General distribution* **–** *known mean rate and variance"*

The operating characteristics of the M/M/s system are denoted by:
λ*= the mean arrival rate for the system*
μ *= the mean service rate for each channel*

Stability condition of a model: Queuing theory establishes this *condition* for each one of the model types. The provision applies when mean service time is less than mean arrival rate; meaning that the probability an arriving customer into a system has of not having to queue upon arriving a system equals to zero (Willig, 1999). It implies that no queuing will be present at a specific point in time in the system. The algebraic expression of the Stability condition is represented as follows (See Equation 1).

Equation 1: Model Stability Condition

$$P_0 := 1 - \frac{\lambda}{\mu}, \text{ where } \lambda > \mu$$

[20] Anderson, Sweeney, & Williams, 2003 & Browne, 2006.

[21] Poisson Process or Distribution: Helps determine the probability distribution for the number of arrivals in a given period of time. For many waiting line situations, the arrivals occur *randomly* and *independently* of other arrivals, and we cannot predict when an arrival will occur (Anderson, Sweeney, & Williams, 2003).

4.3 Samples and descriptions of some queueing models

Although the only queuing model that applies to the ports being analyzed in this particular research is the M/M/2 model, two other simple models will be explained in this section. The intention is to provide a broader scope of the basics of the queueing theory through such an explanation, as well as to explain why the model selected is the proper one for such cases. In total, three models will be detailed in this section.

4.3.1 M/D/1 Queueing model

The M/D/1 system corresponds to a single server system, with infinite waiting room, exponentially distributed inter-arrival times (with parameter λ) and a deterministic or constant service time distribution. The application of this model is seen on automated processes such as queuing discipline viewed at coffee machines service points. The serving time is constant regardless of the customer. In this model, the stability condition previously described applies as well (Anderson, Sweeney, & Williams, 2003). Since service time is fixed in the M/D/1 system, such composition does not apply to the queueing system present in the locations analyzed in this research. The ports researched in this study experience service time variations, due to asymmetric cargo volumes and operational conditions from one vessel to another.

4.3.2 M/G/1 Queueing model

The M/G/1 system has a single server, an infinite waiting room, exponentially distributed interarrival times (with parameter λ) and an arbitrary service time distribution, for which at least the mean value μ and the standard deviation is known. The service discipline is FIFO (Willig, 1999). In this queueing system, service time is known. In the model, the stability condition applies as previously described.

The application of the M/G/1 model is not viable in the scenarios selected in this thesis, as in the ports researched have variable service times. "In this system we have a single server, an infinite waiting room, exponentially distributed interarrival times (with parameter λ) and an arbitrary service time distribution, for which at least the mean value μ and the standard deviation is known. The service discipline is FIFO" (Willig, 1999).

4.3.3 M/M/s Queueing model

The M/M/s model is a multi-channel model with Poisson arrival and exponential service times (Decker, 2009). It applies corresponds to a system with "**s**" service stations in total. The probability distribution for arrials and service times implies that the system is "memoryless", therefore, arrival patterns and service times are unrelated and independent. Finally, arrivals wait in a single waiting line and then move to the first open channel with a FIFO service discipline.[22] [23] Based on the

[22] Ibid.

analysis of the queuing models available, the author of this thesis has concluded that an M/M/s model applies to the analisys of all of the scenarios created; specifically under the M/M/2 modality. The conclusion above is explained by the following analisys.

The arrival pattterns of the vessel in all of the ports studied have no dependance amongst each other. Agribulk vessels are hired by different trading companies aiming to comply with sales contracts subscribed with different clients. Trading companies serve as the vessel charterers as well, same which define the vessels arrival window at load port. Arrival windows are generally established within a fifteen calendar day frame. The chartered vessel can present to the appointed loading terminal anytime within the established frame. On the other hand, information between charterers is not shared among each other. Such conditions for vessel arrival at load port which are non-related and imply high randomness to the loading point arrival pattern, extend to the vessels arrival patterns at the Colombian discharge ports. This serves as a proof to determine that the arrival distributions for the ports analyzed in this thesis are poisson probability distributions (M).

The service times for all of the three ports vary for many different reasons. The first and most important, is that quantities to discharge per vessel are never identical. At an average discharge rate per berth, service times have a variable component. On a second level, unexpected delays during the berthing and discharging process are common. As explained earlier, delays can be caused by weather, burocratic, technical or operational reasons. Last, the fact that berth shifting is a possibiltiy in order to achieve better discharge rates in two of the ports, add another variablility factor to the service process. As such delays are present, the discharge patterns are random and non interdependent. The abovementioned reasons serve as proof to determine that the service time is exponentially distributed (M). Such components have been included in the simulation models in order to have a closer approach to the real operation schemes.

In terms of service channels at each of the three ports, all of them count with two berth positions available for agribulk products discharge. Although the ports of Santa Marta and Cartagena (MEB) have a special condition in which berth shifting is a possibility, the number of service points available is still two. For such reason number 2 has been selected to determine the number of channels at each location. Finally, arriving vessels into the port are lined up in a single waiting line and moved to the assigned berth accordingly, once a channel is opened.

[23] See Annex 3 for explanation on formulas commonly used in this model.

For the abovementioned reasons, the Queueing Model applied in this research is denoted as ***M/M/2*** (See).

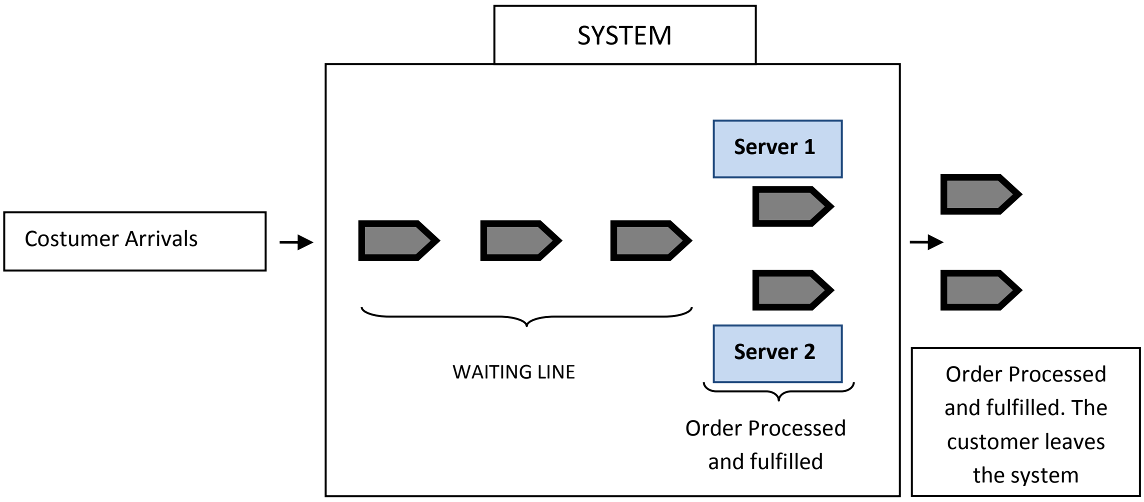

Diagram 13: M/M/2 single waiting line with two service channels

**Source:* Anderson, Sweeney, & Williams, 2003 *& Elaboration of the Author.*

4.4 Literature review

Queuing theory is a valuable tool useful in analyzing, identifying and offering solutions to bottlenecks present in any flow. For that reason, the study of queueing systems has become very popular in different fields. A number of studies have been conducted by a different of researchers specifically on the application of the theory on bulk cargo discharging ports plus their corresponding queueing and congestion problems. Author finds limited literature specific to bulk terminal operations. Nevertheless, the below is well recognized literature for this topic.

Williamson & Daunt, (1982) analyzed the flow of cargo from vessel berthing through discharging and out of the port. The research approached variables relative to the intrinsic capacity of ports in developing countries to handle cargo. Each of the stages was analyzed in order to see the cargo outflow as a pipeline flow.

Altiok (2000) has developed his studies on tandem queues in bulk port operations. In his research, he has been focused on the total time vessels spend in the arrival and completion of loading bauxite in bulk, at a selected terminal in Guinea. His research was based on traffic simulation and provides conclusions and solutions to the queueing problems present at that port.

Lam and Huang (2002) have studied the alternative of a flow-swapping method to reduce congestion in roads. According to their research, a solution to congestion is to be able to “swap” or transfer work easily and automatically to any service station which is not working at a specific point in time. The possibility of the work transfer provides the system with flexibility to increase its throughput capacity. Such condition resembles the berth shifting maneuvers exercised at the ports of Santa Marta and Cartagena (MEB), analyzed in this thesis.

Jagerman and Altiok (2003) together, have focused their research on the discharge operations concerning bulk carrier vessels. Their research has been aimed towards establishing probabilities of delays at ports. Their findings provide information on service time distributions on vessels interarrival times (a) with respect to the vessel arrival window (ω) assigned by the port based vessel scheduled arrival date. The relation between the two variables allows the researchers to establish probabilistic forecasts on when queues can be formed at the ports selected in their study.

Hoque & Biswas (2007) have studied the berthing problem in the port of Chittagong in Bangladesh is analyzed using a multi-server queueing model. Their research models future traffic flows under existing loading and unloading infrastructure. Their research provides guidance on the necessary investments to be made at the port for loading and discharging operations in order to avoid unbearable queues which become as a disincentive for vessels to call the port.

Mandelbaum & Myron (2008) conducted research focused on the review of a queuing model applied at the St. Lawrence River in Canada. The model served as a guide on a project designed to increase the number of locks at the river intending to reduce vessel queuing time entering and leaving the waterway.

Golias, Boyle, & Thofanis (2009) have conducted a reasearch using applied probability models aiming at optimizing the space berth scheduling problem. The model constructed has been based on technique known as Lambda optimal. Their research indicates that through the model, re-optimization of berthing schedules was possible whenever small variations in vessel arrival patterns occurred.

Chapter 5 Data sources and scenarios

The data sources used for this research are built from a compilation of texts articles, computer files and databases. The main source of information used is a database obtained from the private sources of a Colombian ship agency company. After the records from the database in mention were properly arranged for this research, other computer files and models related to the queuing systems were applied to serve as guides and aides for understanding the outcomes. With the data sources available, a model was created, intending to simulate the specific berthing dynamics of each of the three ports in mention. Specific conditions and constraints from each of the three ports have been taken into consideration during the creation of the model.

The scenarios created for this research have been generated under the idea of approaching the simulation as much as possible to the real case scenarios viewed at the port terminals in mention. The berthing procedure has been represented in the model taking into consideration every single step required for such maneuver to take place in real cases. The condition has been achieved by the inclusion of the times and delays each vessels undergoes whilst moving through each one of the steps real berthing and discharge process requires. Specific conditions for each of the terminals have also been considered in terms of berth constraints, discharge rate capacity and any operational characteristics.

5.1 Data collection and description

The data used in this investigation is a complete summary of grain imports executed in Colombia during the year 2008 for the ports of Santa Marta, Barranquilla and Cartagena. The information is a detailed collection of the data reported to the Colombian Customs and Tax Authority (*Direccion de Impuestos y Aduanas Nacionales de Colombia - DIAN*). The data is comprised in a single excel file for research ease. It is a trustworthy and fully valid source of information endorsed by DIAN.

The data file discloses information on every single bill of lading presented to DIAN in Colombia in 2008. A total of 3,328 Bill of Lading entries are available in the data file for the three ports in mention. It contains the following data items per Bill of Lading Reported:

1. Disclosure of cargo classification: Import or Export
2. Type of product package: bulk, containerized or general cargo
3. Colombian port of entry
4. Month in which cargo arrived at the Colombian port
5. Name of vessel on which cargo arrived at the port of entry
6. Local ship agency attending the vessel at port of entry
7. Product name or product description

8. Total tonnage reported on the Bill of Lading
9. Vessel Charterer company or individual
10. Name of shipper
11. Name of the receiver
12. Notify party
13. Port and terminal of Origin
14. Country of Origin
15. Actual date of arrival of vessel at Colombian Port (N.O.R. official tendering time).

The data from the original database has not been manipulated under any circumstance in this research. For this respect, the data contained in the model is a true reflection of the real events viewed at the three Colombian ports in mention during the year 2008. The process followed and the format in which the data has been arranged into, as well as the assumptions considered in the same will be explained in detail in the following pages.

5.2 Data classification

The database has only been filtered and arranged in a manner which is convenient for the data analysis as per the approach given by the author. The data has been organized taking into consideration the information which is strictly required for the research. Any other data has been filtered out of the primary data files created. From the above, the data items which were selected for the analysis the following have been included in the research:

1. Month in which cargo arrived at the Colombian port
2. Name of vessel on which cargo arrived at the port of entry
3. Product name or product description
4. Total tonnage reported on the Bill of Lading
5. Actual time of arrival of vessel at Colombian Port (N.O.R. official tendering time)

The abovementioned data has been classified in a basic ***Primary file*** per port of discharge. Furthermore, using excel tools, tonnages per each vessel have been added together and included in the primary files, in order to identify total tonnage on board per vessel arrival. Using as a basis the scenario viewed in the primary file, other simulated scenarios have been generated per each port; each with specific conditions. Such files are the fields where the different simulations per port have been tested. Further detail on the scenarios created will be described later.

On a second level, a ***Data Analysis file*** has been created per each one of the discharge ports being analyzed. It has been constructed in order to fulfill two primary purposes. The first one is to calculate the real weighted average discharge rates per berth per port with respect to tonnage volumes handled at each facility per year. This has allowed the calculation of averaged discharge rates per berth per port as well as the time at berth per vessel. Such exercise has been followed in order to obtain discharge rate values directly related to the products handled in each port with respect to the quantities discharged. Being able to obtain and use such values allows the study to count with more realistic discharge rates per berth per port, than just using "rule of thumb" discharge rate averages.

The second purpose for creating the Data Analysis file is to identify specific data on each of the scenarios which are useful guidelines during the research. The type of information disclosed, explains figures as cargo volumes discharged per berth or percentage usage of berth per port. Although the abovementioned information does not provide in depth information on the queuing model, it has been used by the researcher as a guideline and a filter to detect any possible errors present, during the model set up phase.

On a third level, one ***Data Summary file*** has been generated per port. The purpose of the file is to summarize information obtained from the Primary Files and the Data Summary files. It is a comprehensive summary which indicates information related to the queuing model applied. It discloses information such as average number of vessels in the system, average time a vessel spends in queue and probabilities that a certain vessel has to queue upon arrival. It has also been used as a tool for quick comparison of results from one simulated scenario to another.

On a second stage, The Data Summary file also provides the results returned by the M/M/2 queuing model applied in the study for each port. Such results are primarily the description of the probabilities a vessel arriving in one of the three ports will have, of find a certain number of other vessels queuing ahead of it. Full detail on the abovementioned files and scenarios will be described on the next chapter. The Data Summary files information is divided into two sections. A first section indicates data related to the operational conditions of the port and variables studied by terminal operators for decision taking and recording objectives. A second section is related to the theoretical approach related to the queuing model used in this study and the results obtained from it.

5.3 Definition of scenarios created

As it has been explained previously in this research, the Primary Files are the core of this study. One basic Primary File is created with the original data for each port. In order to have test scenarios which allow the research to measure the impact of increased cargo volumes, three simulated scenarios were created for each of the ports, based on the information available in the basic Primary File scenario.

In the first simulated scenario per port, the original cargo volumes per vessel have been incremented by 5.00% with respect to the basic Primary File data. The same exercise has been applied to a second and a third simulation, in which volumes from the Primary File have been increased by 7.5% and 10.0% respectively. Such values have been selected in order to represent low, medium and high volume growth situations. These parameters have not been selected at random, instead, they have been chosen from the average growth rates of Colombian grain imports during the period 2005 – 2008 which showed averages of about 10.0% per annum[24]. A benchmark of 10.0% as the high growth case has been considered by the author as a valid value based on observations which indicate that average rates higher than that number are rarely observed in the markets in reference. In that way, it indicates how the ports should be prepared in the future in term of cargo volume increases.

The volume increments of 5%, 7.5% and 10% were applied to the original tonnage each vessel carried. Therefore, the number of vessels calling the ports in the three new simulated scenarios remains unchanged and no new vessels were created. Therefore, the only change applied was the increased tonnage per vessel. The decision was taken under the basis that it will be too difficult and random to decide how much cargo volume should each new created vessel should be assigned. In total, three simulations with their four corresponding volume scenarios were created. The intention of the approach is to be able to view different berth dynamics behaviors at each of the terminals under different circumstances which alter or interrupt the normal development of the flow of the berthing maneuvers and discharge process.

The difference between each of the basic scenarios per port is the application of a random delay component to the vessel's berthing and discharging times. Each basic scenario has its own random delay, which is identically replied on its corresponding 5.0%, 7.5% and 10.0% volume increases. Such delay times have been applied at random using the *random tool* from the Excel program from Microsoft Office 2007. The intention of the inclusion of delays to the different scenarios is to provide real life delay cases or circumstances to the model in order to approach it as much as possible to reality.

The random delay shocks were applied in two different steps of the arrival – berthing – discharging process. The specifics of how the random delay components have been applied into the model will be analyzed further on this text. The result of the application of the mentioned random delay components has been a number of different simulated situations which have added additional queuing and congestion cases to analyze.

Considering this research is focused on the impact of congestion on specific selected ports, only growth cases were tested. The aim of this approach has been, to identify potential congestion problems experienced by tramp handymax bulk vessels arriving at the three terminals mentioned. In such way, the study has been focused on analyzing which additional queuing and congestion situations could rise by increasing the cargo volumes while maintaining the existing infrastructure on the ports unchanged. For those reasons, no volume decrease scenarios have been tested.

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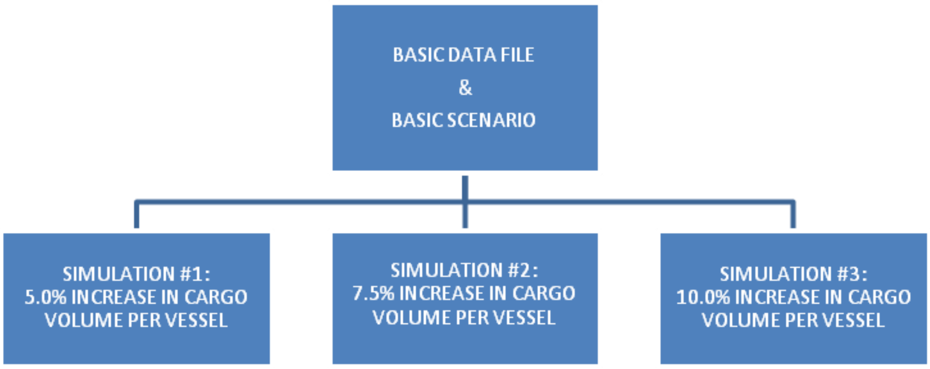
[24] Information based on personal professional experience from the author of this study, corroborated by Naves Colombia S.A. staff.

Summarizing the above, the author of this research established twelve different scenarios per port. Three basic scenarios each with different random delays was constructed based on the cargo volumes per vessel on the data. On top of each of these basic scenarios three additional simulations were constructed to each one of them, in which cargo volumes are increased by a different value each time. The creation of such simulation cases has translated into a total twelve simulations per port for a total of thirty six simulations for the whole model altogether (See Diagram 14).



<u>Diagram 14: Simulation scenarios description scheme</u>

The above simulations have been applied to each one of the three ports analyzed in this research and tested in the model. A total of three of these schemes have been tested on each one of the ports as well, each one of the schemes has been altered by the application of random delay times to the process. The random delay schemes change from one scheme to another but does not change amongst the different volume variation simulations of each basic data file.

Chapter 6 Model application

As it has mentioned earlier in this study, the test model has been set up in Microsoft Excel 2007. The model has been created in order to identify and describe total time at port for each one of the vessels calling.[25] In order to achieve the above, the following criteria and variables have been applied and tested.

6.1 Application of discharge rates per berth per port

The first step taken during the model setup phase was to define specific average discharge rates for each of the A and B berths per port. In order to define the values, a specific weighted average discharging rate was found for each dedicated berth per location. Such a weighted average discharge rate was based on the total tonnage per product unloaded at each specific port with respect to an assigned averaged unloading rate per product as well.[26] As it has been previously mentioned, grains can achieve higher discharge rate averages than meals. In order to decide how to assign the average discharge rates per product, the rule of thumb discharge averages were taken into consideration as well as the rates viewed from personal experience from the author of this research. The exercise returned the following average discharge rates for the dedicated berths (Berth A) of each one of the ports:[27]

- Port of Santa Marta: 5,400.25 mt per day SHINC
- Port of Barranquilla: 5,257.17 mt per day SHINC
- Port of Cartagena (MEB): 5,722.54 mt per day SHINC

Once the specific discharge rates were defined for each dedicated berth per port, a specific discharge rate was assigned to the alternate berths (Berth B) per port. Considering that discharge rates at Berth's B in the ports of Santa Marta and Cartagena are slower than the ones achieved at their corresponding dedicated

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[25] Total time at port corresponds to the time a vessel takes from the moment it tenders its Notice of Readiness, berthing, discharging and departing the corresponding facility.

[26] Dedicated berths are capable of achieving higher discharging rates in the ports of Santa Marta and Cartagena. In both of these ports, the dedicated berths have been named "Berth A". In the case of the port of Barranquilla, the dedicated "Berth A" achieves the same discharge rates as the alternate "Berth B".

[27] See Appendix 1: Berth specific discharge rate calculation table – Port of Santa Marta,

Appendix 2: Berth specific discharge rate calculation table – Port of Barranquilla & Appendix 3: Berth specific discharge rate calculation table – Port of (MEB) berths, an estimated rate selected by the author equivalent to 80% of the calculated rate for Berth A for theses ports was assigned. For the case of the port of Barranquilla, the alternate berth has no unloading rate differential with respect to its corresponding dedicated berth; therefore, the same value has been assigned accordingly. Taking the above conditions into consideration, the following values have been calculated and applied to Berth's B for each port:

-Port of Santa Marta:	4,320.20 mt per day SHINC
-Port of Barranquilla:	5,257.17 mt per day SHINC
-Port of Cartagena (MEB):	4,578.03 mt per day SHINC

6.2 Assumptions

During the research phase of this thesis, a number of assumptions were made in the construction stage of the basic model. The assumptions aim to give the model characteristics which resemble real life operations as closely as possible. Furthermore, they serve as tools to simplify any condition which could make the model too extended and complex.

1. As vessel cargo volumes are increased, an implied idea that larger vessels will arrive at the port is present. Nevertheless, no port or draught restrictions are considered for so called "larger" vessels.

2. Berthing time for vessels in queue is equal to the time of departure of the vessel occupying that same berth immediately before. No time space has been included in the model for ships arriving in immediate sequence one after another at a same dock position.

3. Actual time of arrival of every vessel is equal to the time of entry into the system. Such time is set at 12:01 a.m. for every ship.

4. Actual time of arrival for any vessel which is assigned a berth instantaneously equals to actual time unloading operation begins. No berthing time is considered in the model.

5. Berth shifting time is assumed to be exactly one hour (0.042 days).

6.3 Primary data file composition

The second step followed after defining the average discharge rates per berth per port was to set up the Primary data files for each terminal. The abovementioned files were inserted in their corresponding primary data files as reference. Following that first step, the remainder of the data file was created, by inserting all of the variables required in the model. From such basis, each simulated cargo volume increase was constructed into each port's primary data file.

6.3.1. Vessel actual time of arrival variable

The first variable in the model, located in the ***first column*** of the database is the actual time of arrival of the vessel. It represents the exact date in which the vessel tendered the N.O.R. to the Port Authority. This information has been taken directly from the original database. Based on the order of appearance of the ships, vessel arrivals have been organized in chronological order, with the intention of maintaining the real patterns to unchanged.

6.3.2. Vessel identification

On the ***second column*** of the database, the vessel name can be found. It is a compilation of the different vessels which called each of the ports. A single vessel can appear twice on the database of one port. The reason to double appearance is the possibility that the vessel was chartered more than once during the year to discharge cargo at the same port. A second valid possibility is that a same vessel can discharge cargo in different ports. This occurs whenever a vessel is hired to discharge cargo at two ports under one single charter or, it could have been hired to discharge at two different ports in different periods of time.

6.3.3. Total cargo tonnage per vessel

The ***third column*** corresponds to the total tonnage on board each vessel arrival. The value corresponds to the summation of the tonnages of all the product(s) on board each vessel. It does not identify or disclose the specific amount per product on each ship. So far in the first three columns described, no calculations have been made. The database has only been filtered and arranged to suit the requirements of the research; therefore, the first three columns are used as reference tools.

6.3.4. Time assigned at first berth

The ***fourth column*** indicates the minimum time a vessel will spend at the first berth is positioned at. The information contained in the fourth column, serves as a guidance to identify whether or not, a vessel presents delays at the first dock it is directed for discharging. It is the first column of the file including formulas. The value of the column has been calculated in three different ways, depending on the specific circumstances of each vessel. The first possible circumstance occurs if the vessel is directed straight into Berth A, known as the dedicated berth of any of the ports. Once a vessel is berthed at such position, it will not be shifted to any other dock, bearing in mind, it is the ideal position any of the vessels will seek in order to achieve the fastest discharge rate possible. In the first case, the calculated time assigned equals to the total tonnage on board divided by the specific discharge rate for Berth A as per the results obtained on the first step of the model setup (See Equation 2).

Equation 2: Total time at 1st berth (A)

$$Total\ time\ at\ 1st\ berth = \frac{Total\ tonnage\ on\ board\ the\ vessel}{Average\ discharge\ rate\ at\ Berth\ A}$$

The second possible circumstance occurs only in the two ports where a shifting maneuver is performed (Santa Marta and Cartagena (MEB)). In such a case, any particular arriving vessel is directed to the alternate berth, Berth B, due to the occupancy at the time of Berth A. Vessels discharging at Berth B in those ports will experience a slower berth productivity and will be aiming to be shifted to berth A. This value is calculated by subtracting the time of departure of the vessel from berth B from the time of arrival to berth B. The named values are columns calculated further down the model; the same will be explained later in this chapter (See Equation 3).

Equation 3: Total time at 1st berth (B)

$$Total\ time\ at\ 1st\ berth = Time\ of\ departure\ Berth\ B - Time\ of\ arrival\ at\ Berth\ B$$

The third possible case occurs when a vessel is taken directly to Berth B and the vessel is never shifted to Berth A. A case as previously described occurs for two different reasons. In the case of the port of Barranquilla, it happens because there is no intra-berth shifting, as it has been explained earlier. The second case occurs only at the ports of Santa Marta and Cartagena (MEB) and is viewed, whenever the vessel initially directed to discharge at Berth B is done discharging earlier than the vessel located at position A. Although the aim is to be able to be shifted to the faster discharging position in the example given it is not possible (See Equation 4).

Equation 4: Total time at 1st berth (C)

$$Total\ time\ at\ 1st\ berth = \frac{Total\ tonnage\ on\ board\ the\ vessel}{Average\ discharge\ rate\ at\ Berth\ B}$$

6.3.5. Vessel inter-arrival rate variable

The ***fifth column*** of the model explains the inter-arrival time rate between vessels, to the port. It is a simple calculation in which the time of arrival of a specific vessel *(x)* is subtracted by the time of arrival of the vessel which entered the port, immediately before the vessel being reviewed (*x-1)*. For instance, if a vessel N has arrived at the port on January 10^{th} and vessel M had arrived at the port on January 8^{th}, the inter-arrival rate from N's perspective is two days. The average of all of the inter-arrival rates is useful in a future step of the study for the calculations required on the queuing model. As it can be seen, the value is denominated in terms of days.

6.3.6. Alternate berth random delay variable

The **sixth column** included in the model has been identified as "Berth B Delay". That particular column has only been created in the primary files of the ports of Santa Marta and Cartagena (MEB). It is not applicable in the port of Barranquilla due to the absence of shifting maneuvers at such location. The purpose of the Berth B Delay column is to include a random delay component exclusively to those vessels which used Berth B as their first berthing position during the operation. The basis of such inclusion is to simulate real life delay situations. These cases occur whenever the alternate berth is busy by another carrier forcing the arriving vessel to queue until the position is liberated or any unexpected time loss occurring whilst the berth shifting maneuver was taking place.

A second common berthing delay reason at the alternate berth to the type of vessels being studied in this research is present whenever the discharge process has already begun and a few hours into the operation, a second vessel with higher priority berthing arrives at the pilots' station. Since berth B is only considered as an alternate berth and not a dedicated one for bulk carriers, other types of ships are given right of way. In such case, the abovementioned ships have priority over the agribulk carriers forcing the terminal to anchor the latter for a few hours until the vessels with priority fulfill their corresponding operation. This condition occurs when liner carriers, car carriers, refrigerated vessels or produce vessels call the port. Berthing of these vessels will always be prioritized at any of the berthing positions other than the dedicated berth. As explained previously, the reason being is the fact such ships have tight schedules to comply with in a specific liner loop, belong to a just in time supply chain modality or carry perishable products which require high speed transit from origin to destination to avoid product losses. In such circumstances, the agribulk vessel will remained anchored until either the dedicated or the alternate berth is freed up.

The way in which the delay component value has been calculated is by using the "random" tool from Microsoft Excel 2007. A formula has been given to the program, in which vessels initially anchored at Berth B receive a random delay of either zero, 0.75 or 1.5 days.[28] The numbers selected have been assigned on the basis that any delays occurring during that specific segment of the operation for the reasons above explained can last eighteen to thirty-six hours[29]. Nevertheless, for simplicity purposes, only the abovementioned figures above have been programmed in the model.

6.3.7. Real unloading operation start time

The **seventh column** created into the model is identified as *ATU 1st*. It identifies the real time at which the unloading operation begun on whichever the first berth assigned had been for each vessel. The purpose of the presence of such variable is to be able to visualize actual time in which the real discharging operation begun. Such information allows the model to establish from a numerical standpoint, any time loss at such step in the berthing – discharging – departing process of the ships. The calculation required to get the abovementioned date and time is equal to the actual time of arrival of the vessel at the pilots' station; which corresponds to column number one plus the random delay component assigned by excel to such specific vessel, corresponding to column number six (See Equation 5).

Equation 5: Actual unloading operation start time

$$\boxed{ATU\ 1st\ berth = Actual\ time\ of\ arrival\ at\ Pilots\ Station + Berth\ B\ Random\ Delay}$$

[28] Values represent 75.0% of one day or 18.0 hours & one and ½ days or 36.0 Hours.

[29] Calculation based on personal perception and experience from the author of this study.

6.3.8. General random delay variable

The **eighth column** of the model has been identified as the *Random Delay* column*.* The purpose of the Random Delay column is to include a delay component which accounts for regular or common situations specific to the types of vessel operation being analyzed in this research. The time losses in reference can occur anytime whenever the vessel is in a port, from the moment it tenders the corresponding N.O.R., through the discharge operation and until it done discharging the last grain. Many factors can cause delays during such operations and vary in nature of origin.

The first reason causing such delays in the operation is due to administrative and documentation delay causes. Documents play a heavy role in how seamless the flow of a vessel through a port can be or not. Whenever problems occur due to documents related to, legal, customs or phytosianitary issues, entire operations are held back. In many cases, the reason being the need to present original documents at the port of entry, condition which the author of this thesis considers inexplicable during modern times. Whenever a vessel or a shipment does not have its documents in order, the berthing authorization is delayed. In turn, the discharge process can be placed at a halt if it has already begun or otherwise, the vessel can even be arrested in the most critical situations.

A second group of reasons to expect such types of delays can occur at the waterside. Problems at the ports access channel such as unexpected reductions in its draught, same which are very common in the port in Barranquilla due to its location on the mouth of the Magdalena River (SPRB, 2002). Another factor that can cause delays from the waterside is the variation in tides, which can drastically change the access channel and berth draught conditions. Although this is minor in the three ports under this research it is worth being mentioned.

A third collection of reasons for delays is related to problems directly related to the grain discharging operation, specifically related to the ship-to–shore transfer of the product. The most common problem in this particular phase is rainfall. Grains and meals are agricultural products which cannot get wet. If the product is exposed to rain or water, a decomposition and fermentation process will start immediately, completely damaging the affected lot of grain. The characteristic described above positions those products as “delicate” whenever handled under certain weather conditions. Such condition requires the operation to be completely stopped and the vessel holds have to be closed and sealed every time rainfall starts during the discharging process.

Within the delays presented during the ship-to–shore transfer, wind plays a key role as a delay causing element as well. In cases of extreme wind currents, unloading operations taking place with shore cranes, are slowed down due to the blowing away of the grain or meal from the grabs. In the case of discharge with pneumatic suction equipment, such a factor is less problematic. On top of the two delay causes indicated before, problems with vessel gear, shore cranes, suction devices can be counted as well.

Last but not least, a fourth large group of delay causing scenarios occurs on the shore side of the operation. Delays are caused by the obstruction, by any reason, of the outflow of product from the vessel to the shore. Two main outflow lines of product from the vessel are present in such operations. [30] On one end, the outflow can be interrupted, when the line (usually occurs when a conveyor system is being used) is affected. The problem can be technical but also it can be related to lack of storage space available inside the storage silos. On the other end, the problem can occur at the apron, when the direct discharging operations to trucks is interrupted either by truck traffic within the port premises, at the gate, or due to the lack of trucks readily present to receive products on board alongside the ship. Many other situations conditions can cause delays at the discharge stage; nevertheless, the above are the ones which appear to be more recurrent during the operating.

The model was programmed so that a value of either zero or 0.7 was assigned at random to every single vessel arriving at each one of the ports.[31] In contrast with column number six corresponding to the Berth B Delay, the model was programmed so that any time loss created can apply to all vessels arriving at the port, indistinctively of what berthing order they follow. A vessel that presented a Berth B type of random delay could experience a Random Delay as well; such conditions are not mutually exclusive.

The value selected of 0.7 is one of the assumptions of the model. According to the researcher, such time value is a fair average for the time losses it is aimed to represent. For model simplification purposes, only such number has been selected whenever such delay is present in the model.

6.3.9. Actual time of departure from first assigned berth

The **ninth column** included in the model reflects the actual date and time of departure (ATD) of a specific vessel from whichever berth was assigned **first** for discharge operations (either the dedicated or the alternate berth). The departure time indicated by the model can imply a different situation depending on the specific case of each particular vessel. It is one of the variables that compose the equation of total time at the port which will be explained later in this chapter.

The first case corresponds to the vessels that have been initially assigned to Berth B and sometime into the discharging process at such particular position, Berth A was freed up. For such a case, the value in the column in reference corresponds to the time at which the berth shift took place. The second case corresponds to vessels which entered Berth B, and terminated unloading operations without having the chance to shift to the dedicated berth. In those cases, the actual time of departure from the first assigned position indicates the vessels final unloading operation time. Nevertheless, it does not imply it is the ships real time of departure from port. The reason being that the model has been programmed so that the general random delay variable (eighth column), whenever present on a specific vessels' case, is added to the value ATD of the ninth column. The same condition applies to cases of vessels which were assigned Berth A in the first place which, as explained, are never exposed to shifting. Equation 6 has been used to find such values:

[30] Refer to Diagram 1. - Agricultural grains supply chain.

[31] The value represents 70.0% of one day or 16.8 hours.

Equation 6: Actual time of departure 1st berth

$$ATD\ 1st\ berth = ATU\ 1st\ Berth + Time\ Spent\ at\ Berth + \mathbf{Random\ Delay}$$

6.3.10. Quantity discharged at first berth assigned value

The **tenth column** included in the primary data files from the model revealing total tonnage discharged in the first berth assign to a vessel. It is a reference value used by other cells of the file which will be explained thoroughly later in this text. During the model set up phase it was utilized by the researcher as a guide value useful to find any glitches or mistakes in the model structure. The following equation has been used to find such values:

Equation 7: Quantity discharged at 1st berth

$$Qty.\ Discharged\ @\ 1st\ berth = Time\ Spent\ at\ 1st\ berth \times Berth\ discharge\ rate$$

6.3.11. Total time spent at second berth value

The **eleventh column** created in the model indicates information on how much time a specific vessel spent at the second berth it was initially positioned at. Obviously, it only applies to vessels which underwent a shifting maneuver from a slow berth to a fast berth. For that same reason, such column is only present in the models of the ports of Santa Marta and Cartagena (MEB), since no berth shifting maneuvers are executed at the port of Barranquilla. Equation 8 has been used to find such values:

Equation 8: Time spent at 2nd berth

$$Time\ spent\ at\ 2nd\ berth = \frac{Total\ tons\ discharged\ at\ 2nd\ berth}{average\ discharge\ rate\ applied\ for\ berth\ A}$$

For the cases in which there is no shifting maneuver, the variable “total tons discharged at 2nd berth” will always be zero, making the value of the equation zero as well. On the other hand, the denominator value of the equation will always be calculated using the average discharge rate calculated for berth A at the specific port. The reason being is that the only case when a second berthing is possible is when a shifting maneuver took place which in turn, was only possible from Berth B to Berth A and not vice-versa.

6.3.12. Quantity discharged at second berth value

The **twelfth column** applied to the model indicates the total tonnage discharged at the second berth, whenever used. As it occurs with the previous column, number eleven, it only applies to the ports where shifting maneuvers take place. Again, the value of this column for any vessel which had no shifting scheme will be equal to zero.

The data provided by the twelfth column is a valuable indicator of port berth usage optimization. Depending on the total tons discharged at the Berth B, the usage of such berth can be compared with respect the usage of the fast discharging berth, Berth A. In turn, it is a valuable indicator of how much agribulk dedicated berth and infrastructure under capacity exists at a specific location. The better the port output at Berth A, implies that a lower amount of product was discharged at Berth B. Specific results on such matter for the ports studied in this thesis will be analyzed in the data analysis and results chapter. The values for column number twelve are found using Equation 9:

Equation 9: Tons discharged at 2nd berth

$$\text{Tons discharged at 2nd berth} = \sum \text{tons on vessel} - \text{tons discharged at 1st berth}$$

6.3.13. Actual time of departure & total operation time

The **thirteenth** and **fourteenth columns** of the model are closely inter-related. Total time spent in the full process, or system, per vessel is revealed in such locations. The values returned by such fields serve as indicators which once summed, were used as tools for the analysis of the overall condition of each berth and their corresponding ports. The information of the summed values of each column, compared to ideal berth discharge time usage over the full year 2008, serves as an indicator of how much time loss was observed at each location and can serves as a tool to formulate solutions to improve severe time loss scenarios. Such information will be reviewed in depth in the data analysis section of this study (See Equation 10 & Equation 11).

Equation 10: Actual time of departure

$$\begin{aligned}\text{Actual time of departure} \\ &= \text{Total time spent at 1st Berth} + \text{Actual unloading start time} \\ &+ \text{Random Delays applied} + \text{Total time at 2nd berth}\end{aligned}$$

Equation 11: Total time spent in the system

$$\text{Total time spent in system} = \text{Actual time of departure} - \text{Actual time of Arrival}$$

6.3.14. Total time loss value

The **fifteenth column** included in the model indicates how much time was lost during the full arrival – berthing – discharging and departure process. The outcomes resulting in this segment are some of the most important factors used in the data analysis phase, since they allow the research to assign exact numeric benchmarks to time losses along year for the ports in the analysis. The average delay values per port are also used as elements to determine the probabilities of queueing, when the corresponding queuing model was applied. As for other variables and values analyzed in the primary data file, it has been a useful tool to be able to determine berth usage and berth efficiency indicators. Equation 12 has been used to establish those values:

Equation 12: Time loss

$$Time\ loss = \left(\frac{Total\ tonnage\ on\ board\ vessel}{Average\ discharge\ rate\ for\ Berth\ A}\right) - Total\ discharge\ time$$

6.3.15. Queueing information indicators

The indicators in mention are important sources of information for this study. They serve as guides in the general data summary performed as well as variables in the queuing model applied. From the researcher's point of view, queuing values must be considered as key performance indicators for ports and berths. A total of three types of values are registered under the queueing information indicators segment.

6.3.16. Queue identification indicator

The queue identification indicator programmed in the model, defines if a particular vessel queues, awaiting for berth availability, upon arrival to port. The queue indicator marks a 1 for each vessel queueing before berthing authorization is allowed. The indicator takes into consideration actual time of arrival with respect to actual start time of unloading operation. If the times of such variables differ, a queuing event is marked for the corresponding vessel. The importance of the indicator relies on the fact that the total amount of queuing events for the time period analyzed in each of the models created can be easily measured. This allows the researcher to understand the impact of increased cargo volume or delays in the vessel arrival – berthing – discharge – exit flow.

6.3.17. Total vessels queueing indicator

On the other hand, the total vessels queuing indicator reveals how many vessels are queuing at the time a specific vessel arrives at one of the ports. The number viewed, includes the vessel which is arriving as well, in the outcome data. The importance of such an indicator to this research is that it allows establishing average number of units queuing whenever a waiting line is present.

6.3.18. Total queueing time value

The results returned under this indicator establish the total time a specific vessel queues whenever such an event happens. Queueing time values differ from total waiting time values, as they only make reference to vessels which queued. The result completely ignores any random delay assigned to the specific vessel, and focuses only on the queueing time experienced before granted berthing permission. Equation 13 has been used to establish such values:

Equation 13: Total queueing time

$$Total\ queueing\ time = Actual\ time\ of\ arrival - Actual\ unloading\ start\ time$$

Chapter 7 Data analysis

The data analysis chapter will be approached from three different angles. On a first level, results obtained from a port and berth operational perspective for each of the three locations will be analyzed. These results refer to discharge capacity and time changes viewed as different scenarios were applied to the basic model. On a second level, results obtained from the queuing model applied to the locations will be explained. Such results are focused on averages relevant to service and vessel arrival times to the ports. The third level of data analysis is also rooted out the queueing model applied to each location. It analyses the queuing probabilities vessels might encounter upon arrival to each port for the different scenarios represented in the basic model. The intention of the abovementioned analytical scheme is to provide the thesis with a holistic analysis from an operational and practical perspective as well as from a theoretical and probabilistic perspective.[32]

7.1 Operational data results

Operational data results provide this research with the real information on how the ports and their berths performed over the period of time analyzed. Such results are useful for port authorities and port operators to define operational goals, set benchmarks and compare performance with respect to previous years. The operational analysis in this thesis is based on time loss experienced, total times used for discharging per vessel, berth productivity and shifting events needed, wherever it applies; for each of the ports reviewed.

7.1.1 Time loss analysis

The time loss analysis describes the difference between the minimum times needed to discharge all of the vessels with respect to the real total time used to discharge the vessels at each port**.** Such averages provide a benchmark to port operators where improvements must be implemented throughout the whole process in order to make the operations as seamless as possible. It is important to understand that this indicator also includes random unforeseen delay components which are out of the control of the operation, such as weather or tide related delays. The simulations created in this thesis, which represent cargo volume increases per vessel of 5%, 7.5% and 10% over the real cargo volumes registered serve as tools to identify the impact of any cargo increase on each one of the ports operations.

Starting with the Port of Santa Marta, time loss is increased in the simulations where cargo volumes per vessel were increased. Nevertheless the results indicate that increased cargo volumes do not impact time loss in a 1:1 proportion. On the three different simulations, whenever the basic cargo quantities per vessel were increased by 5%, time loss delays increased in the range of 5.08% to 8.80%. The fact that the abovementioned values are higher than the 5.0% volume augment indicates that the port lacks capacity to reduce delay times for such volume increase levels. In other words, under the current ports conditions, the operation is incapable

[32] A full summary of all of the described in Chapter 7 for each one of the ports, is presented in: Appendices 4 through 6.

of absorbing additional cargo volumes without generating an increase in its average time loss indicator for the year 2008 (See Table 4).

Following the above, when the cargo volumes per vessel were increased from 5% to 7.5% (2.5% volume increase per vessel), results showed that time loss component between the values of such increases ranged between 2.93% and 5.41%. The same condition applies for this test as well. Increased cargo volumes at a level of 7.5% cannot be absorbed by the port without an increase in the average time loss.

Finally, in the third simulation constructed, cargo volumes per vessel were increased from the 7.5% previous stage to 10%. The tendency observed in which time loss rates outnumber the volume growth rates per vessel (2.5% for this test), prevails once more. In this test, time loss increases range between 3.23% and 7.49%. On average, an increase in total cargo volumes by 10.0% at Santa Marta, translates in a 15.95% time loss increase overall.

Table 4: Total time loss analysis per scenario – Port of Santa Marta

PORT OF SANTA MARTA							
Cargo Volume increase per vessel		Time loss increase rate					
		Simulation 1		Simulation 2		Simulation 3	
Simulated	Total	Specific	Total	Specific	Total	Specific	Total
5.00%	5.00%	8.42%	8.42%	5.08%	5.08%	8.80%	8.80%
2.50%	7.50%	2.93%	11.35%	3.36%	8.44%	5.41%	14.21%
2.50%	**10.00%**	3.23%	**14.58%**	3.14%	**11.58%**	7.49%	**21.70%**

Time loss average for the three simulations for a 10.0% cargo volume increase	**15.95%**

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

The Port of Barranquilla returned similar results to those observed for the Port of Santa Mart. Simulations accounting for additional cargo volumes result in increased time loss rate scenarios in proportions exceeding a 1:1 pattern. It is important into account that this port conducts no intra-berth shifting in its berthing pattern. On the other hand, both berths used for agribulk product discharge purposes offer equal average discharge rates. The conditions above should contribute to reduced time loss rates for the different simulations; such hypothesis does not prove right for Barranquilla.

Simulating cargo volume increases of 5.0% per vessel, time loss rates increased in a range between 7.99% and 10.89%. As explained previously, time loss rate of increase being higher than cargo volume increase, indicates a diminishing cargo handling capacity rate. The same characteristics are viewed in the simulation corresponding to a 7.5% increase in which time loss rates increases within a range of 1.92% and 3.92% are viewed. Finally, for an additional 2.5% cargo volume increase, time loss increase rates range from 4.14% to 8.25%. It is clear that the port of Barranquilla experiences constraints whenever the volumes observed in 2008 are exceeded. Average time loss rate increases for the three simulations equate to 18.16% for a 10.0% increase in total cargo volume (See Table 5).

Table 5: Total time loss analysis per scenario – Port of Barranquilla

PORT OFBARRANQUILLA							
Cargo Volume increase per vessel		**Time loss increase rate**					
		Simulation 1		**Simulation 2**		**Simulation 3**	
Simulated	**Total**	**Specific**	**Total**	**Specific**	**Total**	**Specific**	**Total**
5.00%	5.00%	9.13%	9.13%	7.99%	7.99%	10.89%	10.89%
2.50%	7.50%	3.31%	12.44%	1.92%	9.91%	3.92%	14.81%
2.50%	**10.00%**	4.92%	**17.36%**	4.14%	**14.06%**	8.25%	**23.07%**

Time loss average for the three simulations for a 10.0% cargo volume increase	**18.16%**

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

The analysis corresponding to the Port of Cartagena (MEB) reveals a different trend from that viewed on the analysis for the other two ports. In the case of Cartagena, the increase in cargo volume with respect to time loss rate increase follows a proportion of less than a 1:1. The result indicates that the port in mention is in capacity of handling additional cargo capacity, without reducing its operational output.

The study indicates that a cargo volume increase of 5.0% returns time loss increases within a range 2.66% and 4.78%. For the second simulation which corresponds to an increase of 2.5% over the initial increase in volume, time loss increase rates range within a window of 1.11% and 1.65%. Finally, results for the third simulation, corresponding to an additional 2.5% increase in cargo volumes per vessel returns time loss increases ranging from 1.56% to 2.27%. On average, the investigation indicates that cargo volume increases of 10.0% over the basic figures result in an average time loss rate of 7.26%.

From the abovementioned results it can be determined that the port of Cartagena (MEB) currently counts with enough operational capacity to handle larger cargo volume levels without undermining the terminals time performance indicators. This implies that peaks in cargo reception will not affect the terminals operation in a significant manner. It can be mentioned that alterations in port or berth productivity at this location are rarely generated by operational or technical circumstances. For that, it can be stated that Cartagena is a highly efficient location, very attractive for the discharge of agribulk products (See Table 6).

Table 6: Total time loss analysis per scenario – Port of Cartagena

PORT OFCARTAGENA							
Cargo Volume increase per vessel		Time loss increase rate					
		Simulation 1		Simulation 2		Simulation 3	
Simulated	Total	Specific	Total	Specific	Total	Specific	Total
5.00%	5.00%	4.59%	4.59%	1.55%	1.55%	1.56%	1.56%
2.50%	7.50%	2.66%	7.24%	1.65%	3.19%	1.62%	3.18%
2.50%	**10.00%**	4.78%	**12.02%**	1.11%	**4.30%**	2.27%	**5.46%**

Time loss average for the three simulations for a 10.0% cargo volume increase	**7.26%**

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

7.1.2 Time loss specific to queueing events analysis

Time loss analysis reviewed in the previous section provides information on overall time loss events. It includes delays caused by random unforeseen circumstances, as well as to operational delays related to berth shifting and congestion. The analysis on this particular section is focused exclusively on reviewing the results obtained from the data only specific to cases of vessels which queued upon arrival to port. Therefore, it does not contemplate vessels which did not queue at all. The data allows the analysis of time loss caused by the queuing condition. Results from this section provide this thesis with valuable information on the impact of queues on the agribulk vessel operations at each one of the ports studied.

According to the research, the port of Santa Marta experienced a significant number of queueing events for each of the scenarios and simulations created. In some of the simulations up to 43.75% of the total vessels arriving in the port queued upon arrival. Results corresponding to the scenario constructed representing cargo volume increases of 5.0%, increased time loss in a range between 6.45% and 9.65%. On a second level, a further increase in cargo volumes by 2.5% for a total 7.5% generated additional delays in queuing events in a window within 2.59% and 9.65%. Finally, one more increase in cargo volumes by 2.5% for a total 10.0% returned queueing time delay rate increases ranging between 3.04% and 8.10%. The general averaged increase for the time loss for the simulations constructed corresponds to 15.98% (See Table 7 & Table 8).

The data described above indicates that the impact of queues on the overall operation of the port is high. Elevated time value losses allow to us to assert that the port lacks capacity to handle queues and that it will be common to see spiral increases in queues in situations when vessel interarrival time is reduced. The aim of the port must be focused on two fronts. On a first front, queueing events must be avoided as much as possible. On a second front, efforts towards improving service on queueing vessels must be made.

The problematic presented in this section can be improved in two ways; increasing discharging rate averages or increasing berth availability at port. Both solutions take time to be implemented, but also represent high investment costs. The efforts of the port must be guided then on short term solutions that allow reducing the total time vessels spend at the berth, in order to speed up the system flow process. A solution proposed by the author of this thesis will be presented further.

Table 7: Total queueing events count – Port of Santa Marta

PORT OF SANTA MARTA

	BASIC SCENARIO (BS) 1	(BS) +5.0 %	BS + 7.5%	BS + 10.0%
QUEUING EVENTS	17.00	17.00	17.00	18.00
% Of total vessels calling the port	21.25%	21.25%	21.25%	22.50%

	BASIC SCENARIO 2	(BS) +5.0 %	BS + 7.5%	BS + 10.0%
QUEUING EVENTS	28.00	29.00	30.00	35.00
% Of total vessels calling the port	35.00%	36.25%	37.50%	43.75%

	BASIC SCENARIO 3	(BS) +5.0 %	BS + 7.5%	BS + 10.0%
QUEUING EVENTS	23.00	25.00	30.00	30.00
% Of total vessels calling the port	28.75%	31.25%	37.50%	37.50%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

Table 8: Total time loss analysis for queueing events – Port of Santa Marta

PORT OF SANTA MARTA

Cargo Volume increase per vessel		Time loss increase rate					
		Simulation 1		Simulation 2		Simulation 3	
Simulated	Total	Specific	Total	Specific	Total	Specific	Total
5.00%	5.00%	6.45%	6.45%	5.16%	5.16%	9.65%	9.65%
2.50%	7.50%	2.59%	9.04%	3.22%	8.39%	5.72%	15.36%
2.50%	**10.00%**	3.04%	**12.09%**	4.02%	**12.40%**	8.10%	**23.46%**

Time loss average for the three simulations for a 10.0% cargo volume increase	**15.98%**

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

Results corresponding to the analysis on the Port of Barranquilla also show significant time loss increases at queueing events generated by increased import agribulk cargo volume handled. The particular case on time loss for this port is severe, as the results show, a very high volume increase versus time loss increase ration in all of the simulations constructed. Outcomes on this particular indicator show that increased volumes of 5.0% generate increases in time losses for queueing events in a range between 22.05% and 25.83%. An additional increase in cargo volumes by vessel by 2.5% to a 7.5% generates additional time losses in a window ranging from 6.16% to 10.71%. Finally, an additional 2.5% cargo volume increase raising the total to 10.0% increases time loss for this particular variable to between 6.11% and 16.97%. The overall average time loss increase for a 10.0% volume increase of the three simulations accounts for 43.26% (See Table 9 & Table 10).

The marked tendency the port of Barranquilla has on increased time loss on queueing vessels indicates that the terminal operations are highly affected once a queue is formed. In fact, Barranquilla has a higher tendency of experiencing queues, as the average vessel interarrival rate for the period studied is of 3.85 days. In contrast, that figure for the port of Santa Marta is of 4.41 days. Such consideration is very important since the average service times per vessel at Barranquilla for each scenario result in:

Basic Scenario (BS):	3.06 days
(BS) +5.0% cargo volume increase:	3.21 days
(BS) +7.5% cargo volume increase:	3.29 days
(BS) +10.0% cargo volume increase:	3.37 days.

The reduced slack time between average vessel service times and average vessel interarrival rates, generate a high propensity for this port to generate queues for incoming agribulk vessels. Special attention should be given to improve berth productivity to be able to outbalance such negative effects.

Table 9 Total queueing events count – Port of Barranquilla

	BASIC SCENARIO (BS) 1	(BS) +5.0 %	BS + 7.5%	BS + 10.0%
QUEUING EVENTS	17.00	20.00	21.00	22.00
% Of total vessels calling the port	18.09%	21.28%	22.34%	23.40%
	BASIC SCENARIO 2	**(BS) +5.0 %**	**BS + 7.5%**	**BS + 10.0%**
QUEUING EVENTS	14.00	16.00	18.00	18.00
% Of total vessels calling the port	14.89%	17.02%	19.15%	19.15%
	BASIC SCENARIO 3	**(BS) +5.0 %**	**BS + 7.5%**	**BS + 10.0%**
QUEUING EVENTS	16.00	21.00	21.00	23.00
% Of total vessels calling the port	17.02%	22.34%	22.34%	24.47%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

Table 10: Total time loss analysis for queueing events – Port of Barranquilla

PORT OF BARRANQUILLA							
Cargo Volume increase per vessel		Time loss increase rate					
		Simulation 1		Simulation 2		Simulation 3	
Simulated	Total	Specific	Total	Specific	Total	Specific	Total
5.00%	5.00%	23.61%	23.61%	22.05%	22.05%	25.83%	25.83%
2.50%	7.50%	8.00%	31.60%	6.16%	28.21%	10.71%	36.54%
2.50%	**10.00%**	10.34%	**41.94%**	6.11%	**34.32%**	16.97%	**53.51%**

Time loss average for the three simulations	43.26%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

Total queuing events for the port of Cartagena (MEB) are quite a few. Only a small number of vessels queued at such port during 2008. On a percent basis the maximum number of queueing events occurred to 19.44% corresponding to the simulation where total cargo volumes per vessel were increased by 10.0% over the original levels (See Table 11 & Table 12).

Table 11: Total queueing events count – Port of Cartagena

PORT OF CARTAGENA (MEB)

	BASIC SCENARIO (BS) 1	(BS) +5.0 %	BS + 7.5%	BS + 10.0%
QUEUING EVENTS	4.00	5.00	5.00	5.00
% Of total vessels calling the port	11.11%	13.89%	13.89%	13.89%

	BASIC SCENARIO 2	(BS) +5.0 %	BS + 7.5%	BS + 10.0%
QUEUING EVENTS	5.00	5.00	5.00	5.00
% Of total vessels calling the port	13.89%	13.89%	13.89%	13.89%

	BASIC SCENARIO 3	(BS) +5.0 %	BS + 7.5%	BS + 10.0%
QUEUING EVENTS	6.00	6.00	6.00	7.00
% Of total vessels calling the port	16.67%	16.67%	16.67%	19.44%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

Table 12: Total time loss analysis for queueing events – Port of Cartagena (MEB)

PORT OF CARTAGENA (MEB)							
Cargo Volume increase per vessel		Time loss increase rate (in days)					
		Simulation 1		Simulation 2		Simulation 3	
Simulated	Total	Specific	Total	Specific	Total	Specific	Total
BASIC	0.00%		3.25		4.61		6.91
5.00%	5.00%	0.81	4.06	0.33	4.93	1.02	7.93
2.50%	7.50%	0.23	4.29	0.16	5.10	0.38	8.31
2.50%	**10.00%**	0.23	4.52	0.16	**5.26**	0.33	**8.64**

Time loss average for the three simulations	614.07%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

With respect to cargo volume increase values and their effect on total queueing time loss, the total number of queuing events is too, therefore it is not appropriate encompass such changes under a percentage increase perspective. For such reason the analysis will be conducted from a real time loss value angle. The research indicates that time loss increase at Cartagena is very low when increased cargo volumes are simulated at the terminal. In the three scenarios constructed, the maximum increase in such value corresponds to 1.4 days (30 hours total) for the full year.

Different conditions allow such reduced number to occur. On one end, the high discharge rates offered by the port, allow a faster vessel turnaround time. Second, the reduced number of agribulk carriers calling Cartagena (MEB) increases the vessel interarrival time to an average total of 9.48 days. Such an arrival rate in function of average vessel service time, which ranges between 2.15 and 2.51 days per vessel, permit such reduced queuing events. This indicator allows us to infer that Cartagena counts with enough installed capacity to discharge agribulk product cargo volumes tested in the simulations with minor negative impact on the terminal operations. Queueing is not a major issue at such facility.

7.1.3 Total discharge time analysis

Analyzing the total discharge time indicator behavior for each scenario allows us to identify how cargo volume increases per vessel affect the operation of the system as a whole. It includes the waterside operation (arrival and berthing) and the landside operation (discharging and shifting if applicable). The indicator allows us to understand how the system as a whole can handle additional cargo, under the current capacity availability and operational schemes applied. The basic model constructed takes into consideration the random delay variables inserted, same which affect this indicator. For that reason, any delays caused by unforeseen circumstances such as weather or any operational delays are simulated in the model.

This indicator reflects the total time a vessel spent since the moment it enters the system, until it leaves the same. From an operational perspective, time of entry into the system correspond to the N.O.R tendering time. On the other hand, time of exit out of the system corresponds to the time at which the particular vessel fully finished its discharging operation at the port.

The application of the analysis on this indicator on the Port of Santa Marta indicates that increased cargo volumes per vessel, do not affect the total time at port significantly. The outcome can be explained by the fact that the weight of total queueing time over the full year of operations does not add excessive time loss to the port (See Table 13). Such a result points out that total time loss is relevant only when queuing events do occur. The operation on the landside is not affected significantly by the increased volume handling condition. As a result, total operations times are not increased disproportionately when cargo volumes are augmented at the facility.

Table 13: Total discharge time analysis – Port of Santa Marta

PORT OF SANTA MARTA

	Simulation # 1			**Simulation # 2**			**Simulation # 3**		
C.V.I*	5.00%	2.50%	2.50%	5.00%	2.50%	2.50%	5.00%	2.50%	2.50%
T.D.I.I.**	5.34%	2.43%	2.49%	5.10%	2.61%	2.78%	6.16%	3.25%	3.86%
Correlation	**1 : 1.07**	**1 : 0.97**	**1 : 1**	**1 : 1.02**	**1 : 1.04**	**1: 1.11**	**1 : 1.23**	**1 : 1.30**	**1 : 1.54**

**C.V.I.: Simulated Cargo volume increase*

***T.D.I.I.: Increase in total vessel discharge time at port* *

Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

In the case of the Port of Barranquilla, total discharge time analysis returned results which indicate a minor impact on vessels' total time at port for the first two simulations (See Table 14). In these first two cases, some indicators show slight proportional increase in the total vessel discharge time with respect to the simulated cargo volume increases, nevertheless these rates can be considered minimum. Interestingly, the third simulation does show a significant increase in time delays which is worth to be mentioned. The reason why large delays occur is due to the formation of queues which the terminal cannot handle fast enough. The condition worsens as new vessels arrive, increasing the queuing vessel number. For abovementioned reasons, the main delay problem occurs during high congestion periods, where vessel interarrival rates are very low.

It is important to bear in mind the main distinction between the simulations is based on the fact that different random delay conditions are applied to each one of them. For such reason, the specific delay conditions relevant to the third simulation have conformed a setting where queues build up, increasing total time in the system for such scenario. As per the above arguments, it is valid to infer that cargo volume increase does not significantly impact total vessel time at port.

Table 14: Total discharge time analysis – Port of Barranquilla

PORT OF BARRANQUILLA

	Simulation # 1			Simulation # 2			Simulation # 3		
C.V.I*	5.00%	2.50%	2.50%	5.00%	2.50%	2.50%	5.00%	2.50%	2.50%
T.D.I.I.**	8.50%	3.20%	5.29%	7.84%	3.25%	2.67%	10.45%	3.77%	7.63%
Correlation	**1 : 1.7**	**1 : 1.2**	**1 : 1.82**	**1 : 1.57**	**1 : 1.3**	**1 : 1.07**	**1 : 2.09**	**1 : 1.51**	**1 : 3.05**

**C.V.I.: Simulated Cargo volume increase*

***T.D.I.I.: Increase in total vessel discharge time at port*

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

Results for the port of Cartagena (MEB) differ from those of the other two ports. The proportion between cargo volume increases and with respect to total vessel time at port is less than 1: 1 for all the simulations constructed (See Table 15). As the two variables do not grow at the same rate, it can be determined that the operation at Cartagena can handle more cargo without any negative impact on the process. Total discharge time analysis reinforces the statement presented by the author, indicating that this port has enough installed capacity to handle growing agribulk cargo volumes.

Table 15: Total discharge time analysis – Port of Cartagena (MEB)

PORT OF CARTAGENA (MEB)

	Simulation # 1			Simulation # 2			Simulation # 3		
C.V.I*	5.00%	2.50%	2.50%	5.00%	2.50%	2.50%	5.00%	2.50%	2.50%
T.D.I.I.**	4.59%	1.55%	1.56%	2.66%	1.65%	1.62%	4.78%	1.11%	2.27%
Correlation	**1 : 0.98**	**1 : 0.62**	**1 : 0.62**	**1 : 0.53**	**1 : 0.66**	**1 : 0.65**	**1 : 0.96**	**1 : 0.44**	**1 : 0.91**

**C.V.I.: Simulated Cargo volume increase*

***T.D.I.I.: Increase in total vessel discharge time at port*

**Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

7.1.4 Queuing events analysis

Identifying the total percentage of arriving vessels which queued at a particular port, is a useful tool to understand how the system as a whole is performing in terms of discharge capacity allocated. High percentages of queuing ships over the total number of ships arrived in a specific period of time, indicates that the port is lacking operational performance. The indicator serves as a complement to all the other operational results explained earlier.

Reviewing the case of the Port of Santa Marta, it is clear that a high number of vessels had to queue upon arrival to this port. Values for each different scenario vary substantially in each scenario. The results for the first scenario range in the lower 20% percentile, whilst results for the second and third scenarios range in the upper 30% to 40% range approximately. The conclusion for such a high divergence from one scenario to another is that under the current port scheme, queuing is highly volatile and no real predictable range can be identified. The reason for such a high volatility is based on the fact that the impact of variations in the overall vessel arrival scheme from one scenario to another on the ports capacity to control queues is very high. Bearing in mind that the differences between scenarios are based on the different random delays applied to each in the model, the volatility must be based on such condition. Therefore, it can be implied, that random delays, allow high variation in number of vessels queueing over a sample of time. Although random delays are difficult to control and predict, mechanisms preventing them, or preparing for when they occur, would significantly improve this indicator.

It is also important to analyze the average vessel inter-arrival rate for this port, which is of 4.41 days. The value of this average compared to the average discharge times available for vessels in each scenario are very close. Such times range between 3.63 and 4.01 days in the different simulations. Such a small gap of time creates a higher tendency to observe a vessel queueing in the port, as any minor variation in the average service time will overlap with the average inter-arrival rate, making the queuing condition critical in this port (See Table 16).

Table 16: Percentage of vessel wich queued upon arrival per scenario – Port of Santa Marta

	Simulation	BASIC	5.0% increase	7.5% increase	10.0% increase
SCENARIO 1	**% of vessels which queued**	21.25%	21.25%	21.25%	22.50%
SCENARIO 2	**% of vessels which queued**	35.00%	36.25%	37.50%	43.75%
SCENARIO 3	**% of vessels which queued**	28.75%	31.25%	37.50%	37.50%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

The case of the Port of Barranquilla shows a high number of queuing vessels upon arrival as well. The three scenarios range within similar windows standing in the upper 10% and mid 20% percentile ranges. Uniformity within the queuing event pattern can be explained by the fact that the Bert B Delay component is not present in this port, as no shifting events are present. Such condition opens fewer windows for the vessels to experience unexpected delays which can cause queues in the system. Nevertheless, the high percentage of queueing vessels over total arrivals is a variable to keep in mind, and indicates that the system is still highly affected by volatile total vessel time patterns in the system. It is important to keep in mind that the average vessel inter-arrival rate for this port is of 3.85 days, which is just short of the average discharge time available for each scenario. Such times for the basic, 5.0%, 7.5% and 10.0% increases are 3.06, 3.21, 3.29 and 3.37 days respectively.

The same condition applies in Barranquilla, as in Santa Marta, in which the time gaps are small, and any condition that increases a vessels time in port, increases the probability for other vessels behind it of having to queue (See Table 17).

Table 17: Percentage of vessel with queued upon arrival per scenario – Port of Barranquilla

SCENARIO 1	TOTAL CARGO ICREASE	BASIC	5.0%	7.5%	10.0%
	% of vessels which queued	18.09%	21.28%	22.34%	23.40%

SCENARIO 2	TOTAL CARGO ICREASE	BASIC	5.0%	7.5%	10.0%
	% of vessels which queued	14.89%	17.02%	19.15%	19.15%

SCENARIO 3	TOTAL CARGO ICREASE	BASIC	5.0%	7.5%	10.0%
	% of vessels which queued	18.09%	22.34%	22.34%	24.47%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

The Port of Cartagena (MEB) sows a relatively low value of queueing vessels in its sample. Although on the third scenario constructed, values raise close to 17.0%, it is not the norm for all of the other cases which are closer to the 10.0% values. The main reason for the low percentage of queuing vessels is without doubt the high inter-arrival rate of vessels which averages 9.78 days. Such value compared to the average discharge time available which in no case surpasses 2.5 days, allows the author to infer that statement. As a result, this port is in capacity to absorb variations in discharge times without being severely affected on its average queuing vessel indicator (See Table 18).

Table 18: Percentage of vessel with queued upon arrival per scenario – Port of Cartagena (MEB)

SCENARIO 1	TOTAL CARGO ICREASE	BASIC	5.0%	7.5%	10.0%
	% of vessels which queued	11.11%	13.89%	13.89%	13.89%

SCENARIO 2	TOTAL CARGO ICREASE	BASIC	5.0%	7.5%	10.0%
	% of vessels which queued	13.89%	13.89%	13.89%	13.89%

SCENARIO 3	TOTAL CARGO ICREASE	BASIC	5.0%	7.5%	10.0%
	% of vessels which queued	16.67%	16.67%	16.67%	16.67%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

7.1.5 Alternate berth usage

As it has been explained, the ideal scenario for a vessel is to be able to be directed to the berth offering the highest discharge rate in a port, without any queueing or shifting from one position to another. For such reason, any time the above situation is present, time loss and efficiency are lost in the discharge operation. The highest amount of tons discharged at the dedicated berth, implies the less cost for the supply chain participants and the first best option for the operation.

At the Port of Santa Marta, a range between 23 to 27 vessel shifting events occurred in all the simulations executed. A total of 80 agribulk product vessels arrived in 2008 at this port, resulting in about 30.0% (approx.) of vessels requiring intra-berth shifting during that year. The fact that such a high number of vessels were shifted implies that the alternate berth (Berth B) had to be used in many occasions. Figure 1 depicts the percentage of total cargo discharged at either Berth A and/or B at this port. The figure indicates that for all simulations per scenario, the cargo percentage discharged at Berth B approximated 20.0%. From another approach, it can be stated that approximately 20.0% of the total agribulk products unloaded in Santa Marta in 2008, did not receive fully efficient discharge output. This indicator allows the author to infer, that the dedicated berth efficiency must be increased substantially by increasing discharge rate capacity.

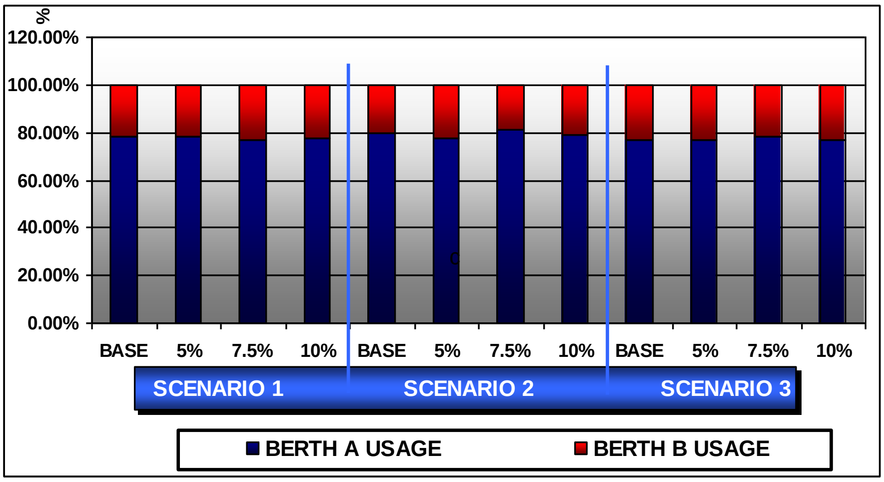

Figure 1: Berth usage with respect to total tons discharged at each position – Port of Santa Marta

* Source: Elaboration of the Author.

The Port of Cartagena (MEB) has a reduced number of intra-berth shifting events during the year 2008 for the selected positions. The number of shifts ranges between 5 and 7 within the different scenarios created. Such range accounts for about 17% of total vessel calling this port. Although the number of shifting berths is not so low, it is important to observe the total tons discharged at each berth per scenario to establish any inefficiency on this matter.

Different results are observed for each scenario constructed with respect to the percentage of total tons discharged at Berth B. The first scenario indicates that for each simulation, Berth B was used to discharge about 14.0% of the total agribulk grains in 2008. Although it is not a high figure it is still elevated taking into consideration the good conditions this port has demonstrated on other indicators analyzed. However, results for the second and third scenarios and their corresponding simulations indicate percentages as low as 6.65% and no higher than 11.67%. Such results appear to be quite low, indicating, that dedicated berth usage inefficiency to be relatively low (See Figure 2). [33]

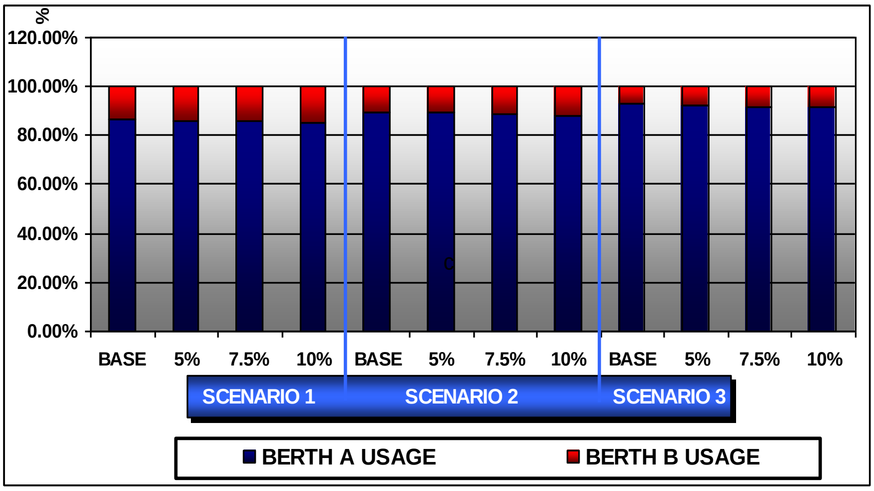

Figure 2: Berth usage with respect to total tons discharged at each position – Port of Cartagena (MEB)

* Source: Colombian Import Statistics Database: Naves S.A. & Elaboration of the Author.

7.2 Queueing model data results

"Waiting Line Models consist of mathematical formulas and relationships that can be used to determine the **operational characteristics** (performance measures) for a waiting line" (Anderson, Sweeney, & Williams, 2003). Considering such statement, the results obtained from the variables specific to the Queueing Model applied serve as a complement to the result obtained from the operational analysis. A number of variables are analyzed under this section, which allows the researcher to establish in further depth, the situation of the three ports analyzed in this thesis. The information provided by the queueing model indicators are based on service times at berth, vessel interarrival rates and average queueing times.

[33] The Port of Barranquilla will not be analyzed under this indicator, as no intra-berth shifting is performed at that location and berth average discharge rates for Berths A & B are equal to each other.

7.2.1 Average number of units in queue

The first parameter analyzed is the "average number of units in queue" denoted as (Lq). This variable indicates the average number of units in the waiting line. The value allows the researcher to understand how critical the queueing condition of any system is in a selected time frame. It is important to understand that the value of this variable in the models constructed has a condition that must not be forgotten. The fact that vessel arrivals at each port in the study do not occur during each of the 365 days of the year analyzed, the Lq value is relatively low. The reason for such outcome stands on the basis that the variable takes into consideration each day of the year, reducing the average substantially.

Nevertheless, the number is a useful tool, to understand the general queuing situation of the port all through the year. It does not offer results exclusive to queueing situations; generally caused during peak seasons with low vessel inter arrival rates. For the reasons above, the Lq variable indicates how much additional tonnage handled at a port affects queues in the system and how the operational characteristics of the waiting line are improved or impoverished.[34] It can be used by as a tool to measure improvement or decline in queue handling strategies.

Starting with the Port of Santa Marta, the initial remark that can be done is that simulated cargo volume increases do not translate into unusual augmentation of the Lq parameter in any of the simulations modeled (See Figure 3). This result allows us to infer, that the general vessel entry operation throughout the year, can be managed without major inconveniences and average queuing levels are not significantly affected for that period of time. In order to see the impact of volume increases during high arrival peaks, the average vessel queueing indicator must be analyzed. As mentioned earlier, this parameter averages queues throughout the period studied.

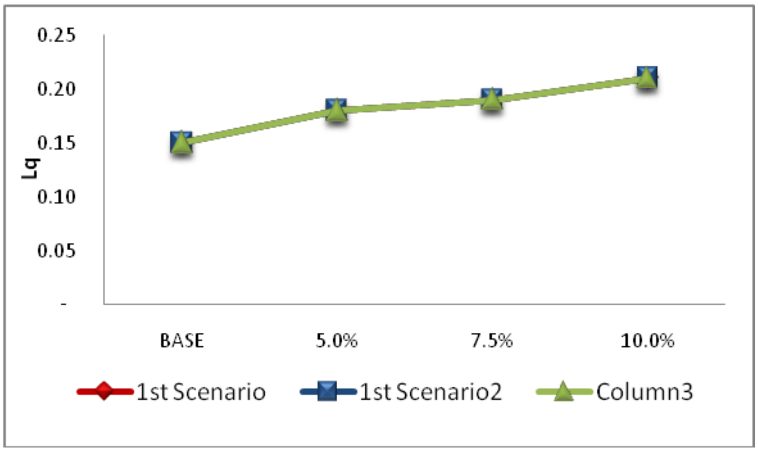

Figure 3: Average number of vessels in queue (Lq) per scenario - Port of Santa Marta

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

[34] Ibid – page 538.

The Lq indicator for the simulations applied to the Port of Barranquilla and Cartagena (MEB) follows a similar pattern observed in Santa Marta (See Figure 4 & Figure 5). The indicator shows minimal variations on the different simulations constructed for each port. The conclusion for the results returned for case of these two ports is the same as for Santa Marta. An insignificant impact on the Lq parameter is generated by increase cargo volumes at the ports under review.

It is important to recognize that the Lq results for the port of Cartagena (MEB) are notorious due to the very low values returned. The Lq indicator shows that the average units in queue for each simulation are less than 1 vessel approaching the value of zero. The significance of the results for such port is that finding a queue at the port is quite highly unlikely.

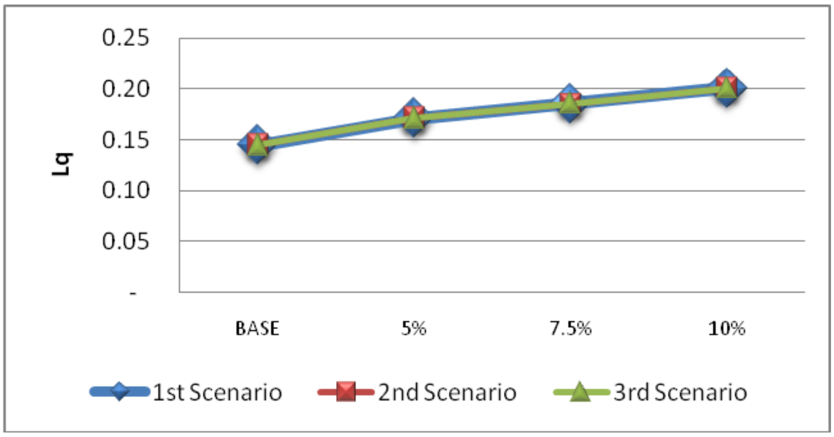

Figure 4: Average number of vessels in queue (Lq) per scenario - Port of Barranquilla

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

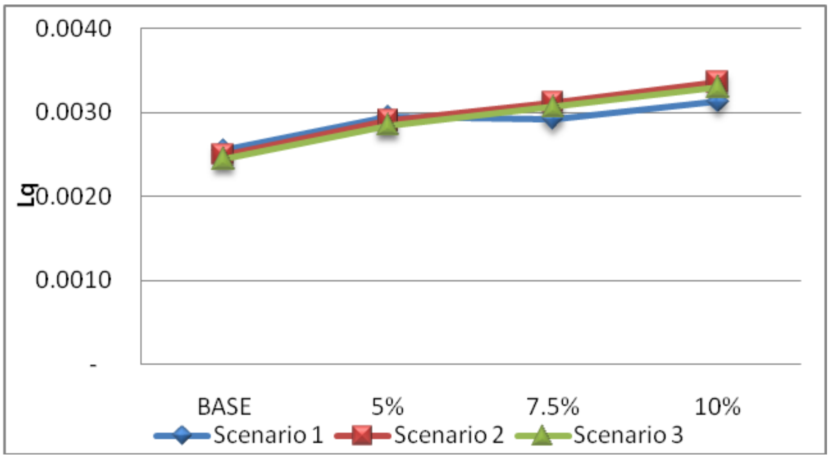

Figure 5: Average number of vessels in queue (Lq) per scenario – Port of Cartagena (MEB)

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

7.2.2 Average time a unit spends queueing

This indicator identifies the negative effect the formation of queues has on the port. It is identified by the notation (Wq). Since it is a measure of time, it is a major variable that has needs to be monitored by port authorities. In many cases, queues are unavoidable due to infrastructure constraints or weather conditions. The Wq indicator serves as a tool to compare port performance from one period of time to another, helping to identify the results of infrastructure and operational improvements at the facility. Efforts in maintaining low average queuing times at ports will relieve stress on the supply chain and will reduce the total port costs. The result will immediately be perceived in the figure of a reduction on the barriers such time loss generates on trade.

In the analysis of the Wq variable it is important to bear in mind that the indicator averages out all of the days in the year, including days where no vessels arrived at the ports. Such a condition returns a relatively low on the average queueing of vessels. However, to have a complete frame of specific queueing characteristics of each port, it is important to complement this theoretical variable with the operational variable "time loss specific to queueing events".

The Wq indicator for the Port of Santa Marta returns results which from the authors' point of view are very high. Within the different scenarios created and their related simulations, the Wq time ranges between 18.87% and 33.40% of the time the vessel will spend discharging at berth (See Table 19).[35] The result indicates that on average, a vessel arriving in Santa Marta will waste the equivalent to almost 1/5th of discharge productive time, waiting in a queue. This condition is of major importance, as it discloses how heavy, the burden of queues is on vessel at this terminal is. According to the model, plenty of space for improvement is achievable.

Table 19: Average time spent in queue vs. berth service rate relation - Port of Santa Marta

	Cargo Volume Increase	Avg. Berth Service Rate (1/µ)	Wq	Wq / (1/µ)
SCENARIO # 1	BASE DATA	3.64	0.69	**18.87%**
	5.00%	3.83	0.84	**21.93%**
	7.50%	3.84	0.95	**24.74%**
	10.00%	4.01	1.05	**26.20%**
SCENARIO # 2	BASE DATA	3.63	0.76	**20.96%**
	5.00%	3.82	0.95	**24.84%**
	7.50%	3.89	1.06	**27.28%**
	10.00%	4.00	1.17	**29.25%**
SCENARIO # 3	BASE DATA	3.65	0.88	**24.11%**
	5.00%	3.83	1.07	**27.92%**
	7.50%	3.91	1.19	**30.41%**
	10.00%	4.01	1.34	**33.40%**

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

[35] Average berth service rate is denoted as *1/µ*

The Port of Barranquilla returns results indicating a high Wq indicator. This means that loss of time prior to vessel arrival to discharge operations, heavily impacts the systems performance as a whole (See Table 20). Queued vessels experience excessive waste of time idle at anchorage waiting for berth.

Table 20: Average time spent in queue vs. berth service rate relation - Port of Barranquilla

	Cargo Volume Increase	Average Berth Service Rate (1/μ)	Wq	Wq / (1/μ)
SCENARIO # 1	BASE DATA	3.06	0.56	18.40%
	5.00%	3.21	0.66	20.68%
	7.50%	3.29	0.72	21.89%
	10.00%	3.37	0.78	23.16%
SCENARIO # 2	BASE DATA	3.06	0.56	18.40%
	5.00%	3.21	0.66	20.68%
	7.50%	3.29	0.72	21.89%
	10.00%	3.37	0.78	23.16%
SCENARIO # 3	BASE DATA	3.06	0.56	18.40%
	5.00%	3.21	0.66	20.68%
	7.50%	3.29	0.72	21.89%
	10.00%	3.37	0.78	23.16%

** Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.*

In contrast with the last two ports described, the results on the Wq versus (1/μ) relationship for Port of Cartagena (MEB) are impressive. The indicators for the simulation ran on each scenario do not exceed 1.40%, meaning that queueing time is only minimal with respect to the vessel service rate at berth (See Table 21). From this indicator we can conclude that the pipeline flow of berthing – cargo discharging and exiting the port, is nearly seamless. Although efforts must be done to progress, small space is available for improvement for these types of operations.

Table 21: Average time spent in queue vs. berth service rate relation - Port of Cartagena (MEB)

	Cargo Volume Increase	Avg. Berth Service Rate (1/μ)	Wq	Wq / (1/μ)
SCENARIO # 1	BASIC	2.1892	0.0259	1.18%
	5%	2.3006	0.0300	1.30%
	7.50%	2.2902	0.0296	1.29%
	10%	2.3435	0.0317	1.35%
SCENARIO # 2	BASIC	2.1750	0.0253	1.16%
	5%	2.2862	0.0294	1.29%
	7.50%	2.3428	0.0317	1.35%
	10%	2.3995	0.0341	1.42%
SCENARIO # 3	BASIC	2.1592	0.0248	1.15%
	5%	2.2721	0.0289	1.27%
	7.50%	2.3282	0.0311	1.34%
	10%	2.3850	0.0335	1.40%

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

7.3 Probabilistic data results

Probabilistic data results are directly linked to the results obtained from the queueing model data results described in section 7.2. The results described in this section are focused on describing the likelihood a vessel would encounter upon its arrival at a specific port of finding other vessel ahead of it in the system. Such vessels could be either at berth or queueing. For that reason, it allows to identify the probability a vessel has on queuing in a system. In contrast, the results from the previous section are aimed on portraying descriptive information on average values related to queuing times and formations and times.

The results on the queuing model for the Port of Santa Marta for this section, returns indications that the probabilities of a vessel finding other ships present or queueing at berth are not very high. This condition applies to all of the simulations constructed for such port. The first indicator, denoted as: "Probability that no units are in the system", returns the highest probability of occurrence with average around 40.0% for all of the simulation (See Figure 6, Figure 7 & Figure 8). [36] & [37]

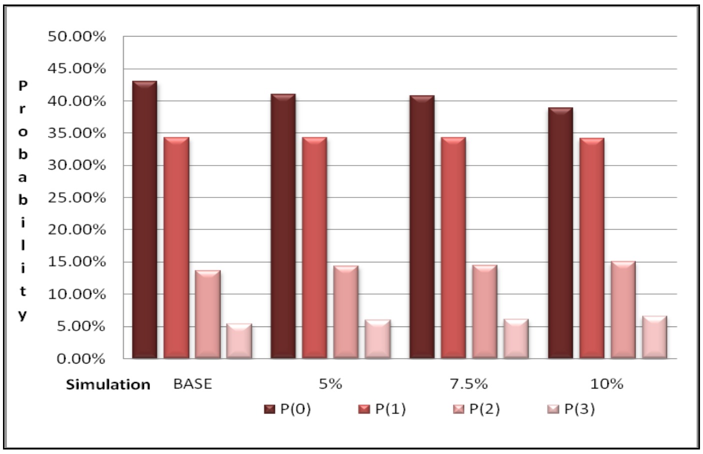

Figure 6: Probabilities of finding a determined amount of units in the system – Port of Santa Marta – Scenario 1

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

[36] Term selected from Anderson, Sweeney, Williams, 2003.

[37] Term can is identified as (P_0) for simplicity. Notation for the probability of N number of units in the system: (N).

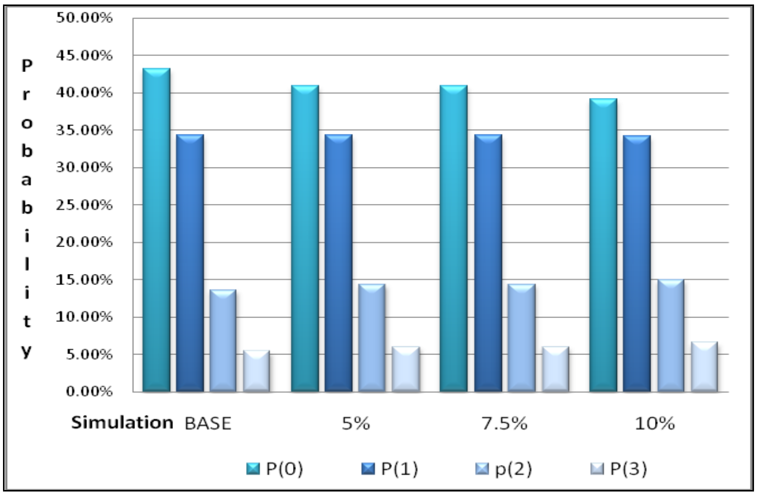

Figure 7: Probabilities of finding a determined amount of units in the system – Port of Santa Marta – Scenario 2

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

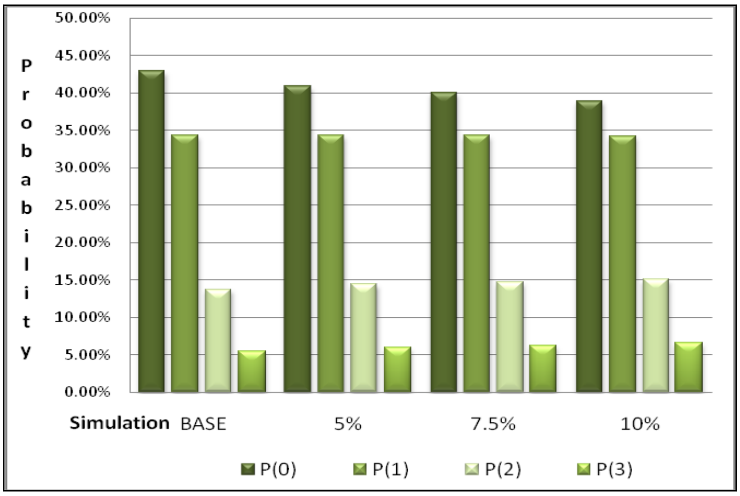

Figure 8: Probabilities of finding a determined amount of units in the system – Port of Barranquilla – Scenario 3

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

Results corresponding to P_1 indicator appear to be high as well, ranging in the vicinity of 35.0% for each of the simulations. In turn, the (P_2) indicates a probability close to 15.0% for each simulation. Considering the berth configuration and berthing dynamics for Santa Marta, congestion occurs whenever more than two ships are in the system. The condition implies that both berths are busy discharging, and a third or more incoming vessels will queue. As per the above criteria, results suggest that probabilities of queuing are relatively low. It means that the number of berths available and operational scheme, are the proper ones. Therefore, neither additional berths nor operational schemes are required to handle discharging operations of agribulk product vessels.

The analysis corresponding to the Port of Barranquilla returns similar results to those obtained from the Port of Santa Marta. Probabilities of having a number of vessels in the system lower than three, is low (See Figure 9, Figure 10 & Figure 11). According to the results presented, the berth assignment and operational scheme for this port is adequate with respect to the probabilities of having more vessels than the system capacity allows.

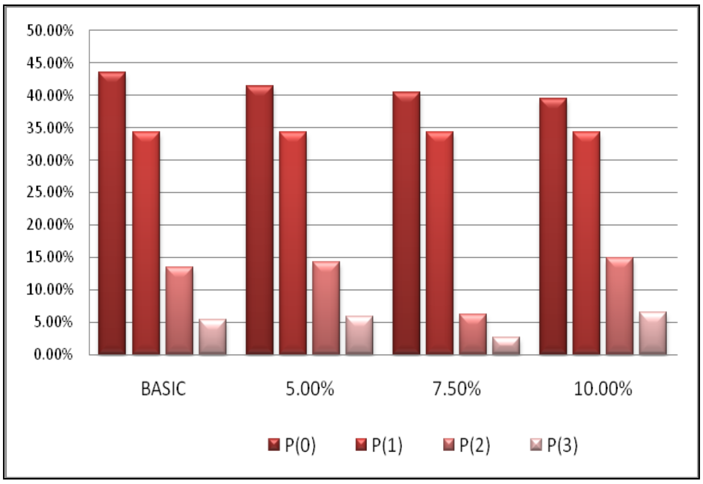

Figure 9: Probabilities of finding a determined amount of units in the system – Port of Barranquilla – Scenario 1

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

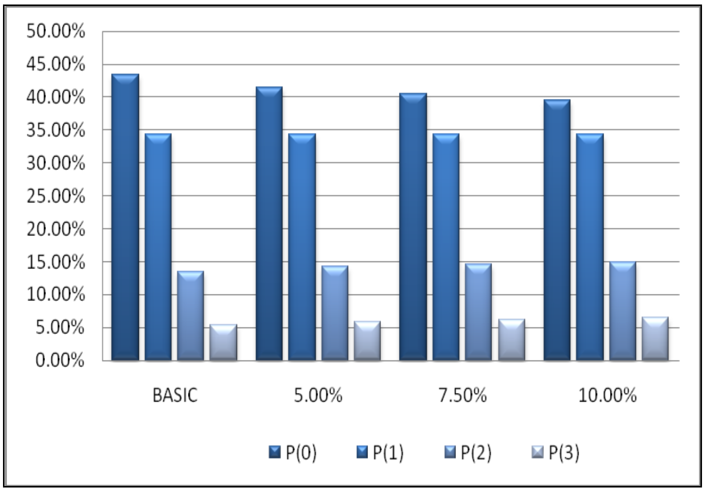

Figure 10: Probabilities of finding a determined amount of units in the system – Port of Barranquilla – Scenario 2

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

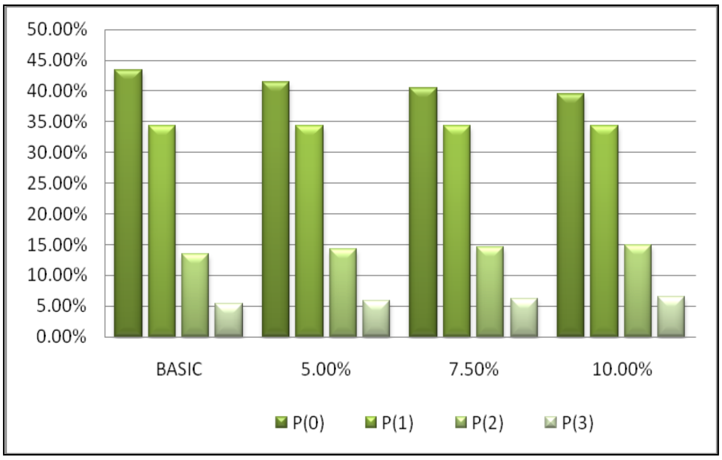

Figure 11: Probabilities of finding a determined amount of units in the system – Port of Barranquilla – Scenario 3

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

Interesting results are observed in the case of the Port of Cartagena (MEB). The data returned by the queueing model points out an extremely low probability of finding congestion scenarios at the terminal. The (P_0) indicator revolves around 80.0% for every single scenario and simulation constructed. Following the (P_0) indicator, the (P_1) ranges in the 10.0% and 1.0% for (P_2) (See Figure 12, Figure 13 & Figure 14). The abovementioned data configures a scenario in which congestion in the port is rarely formed. It is important to point out that these indicators allow this research to confirm that the infrastructure and operational scheme supplied by the Port of Cartagena (MEB), are highly adequate with respect to the requirements arriving vessels demand.

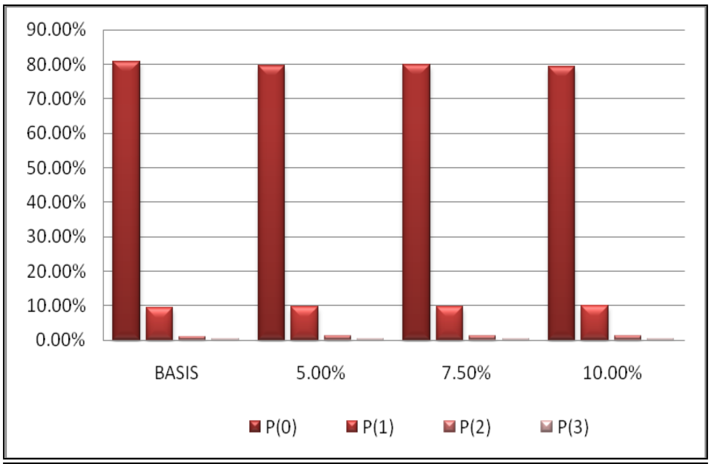

Figure 12: Probabilities of finding a determined amount of units in the system – Port of Cartagena (MEB) – Scenario 1

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

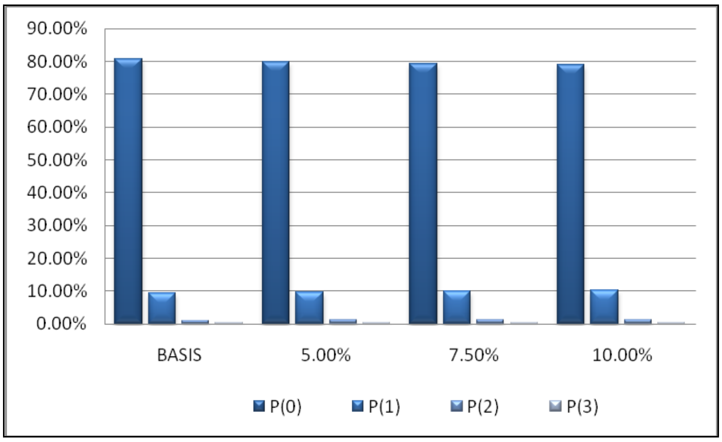

Figure 13: Probabilities of finding a determined amount of units in the system – Port of Cartagena (MEB) – Scenario 2

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

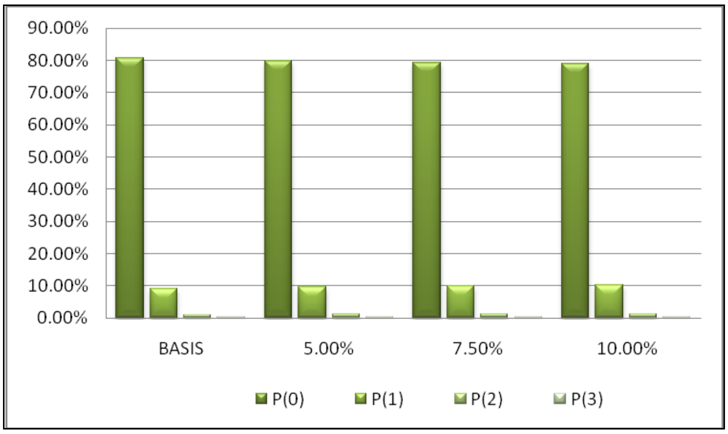

Figure 14: Probabilities of finding a determined amount of units in the system – Port of Cartagena (MEB) – Scenario 3

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

Chapter 8 Barge network as an alternative to queue reduction

The results exposed in Chapter 7 indicate there is room for improvement in terms of queue formation handling, particularly at the ports of Santa Marta and Barranquilla. Being able to reduce queueing time is a major challenge for each of these locations, in order to improve the pipeline type of vessel flow desired in and out of the berths. Different alternatives are possible in order to improve queueing conditions. As explained by Anderson, Sweeney & Williams (2003), "service rates are obtained by making either or both of the following challenges:

1. Increase the mean service rate μ by making creative design change or by using new technology.

2. Add service channels so that more customers can be served simultaneously."

The application of the two abovementioned solutions to the particular cases of Santa Marta and Barranquilla would imply:

1. Dedicating higher efficiency discharging technology at berth. Examples could be to bring into service faster discharging suction equipment or place larger shore cranes with more cargo discharge capacity per move, in order to increase the discharge tonnage per hour rates.

2. Build or assign additional dedicated berths to agribulk vessel discharge in order to increase exclusive service channels to such types of cargo vessels.

Investments in either or both of the above are necessary and are medium to long term solutions to the relevant problematic of these ports. Nevertheless, creativity is very important to keep in mind whenever loading and discharge operations are being handled. Alternatives which provide ease, flexibility and fast solutions on the short run must also be considered in the effort of improving performance. Keeping in mind the queue formation problem is generated at the berth point; short term solutions must not be aimed at attacking the problem at such level, where constriction is already present but along the queue itself. Doing so implies that service should also be provided, even if partially, before the vessel reaches its assigned berthing position. This will reduce vessel's time at berth, therefore reducing queuing waiting time problem.

The solution proposed in this study is based on the above principle. The proposal presented by the author is based on analyzing and simulating the implementation of a basic barge system, in which barges are sent to queueing vessels during their waiting time to discharge partial lots of bulk cargo. Such operation should take place whilst the vessels await at anchorage for berth assignment instructions. The model proposed has been tested on each of the simulations presented in the previous chapters and results obtained have been compared to establish any benefits and advantages, if any of its implementation. [38]

[38] In view of the reduced number of queueing events and the short length the same presented for the results corresponding to the Port of Cartagena (MEB), the author has decided not to test the barge system on this location. Results of the solution at this location would be of limited relevance.

8.1 Description of proposed barge system solution

Implementing a flexible and efficient barge system which allow the reduction of “queuing cargo tonnage”, serves as a viable alternative to consider whenever severe congestion episodes are present in ports. The mechanics of the proposed solution are composed by the following scenarios and steps:

1. Vessel arrival at Pilot’s station.
2. Vessel positioned at anchorage area to wait in queue
3. Barge convoy sent from port and moored alongside queueing vessel.
4. Ship-to-barge bulk cargo discharge operation commences.
5. Berthing position emptied at port.
6. Ship-to-barge discharge operation suspended
7. Vessel sailed into port to assigned berth
8. Barge convoy sailed into port area.

A) Cargo is discharged from barge to either land transportation or silos
B) Barges serve as floating storage for cargo to be stored in until further notice.
C) Barges sailed via inland navigation waterways to appointed hinterland destination.

The above dynamics are explained graphically in Diagram 15.

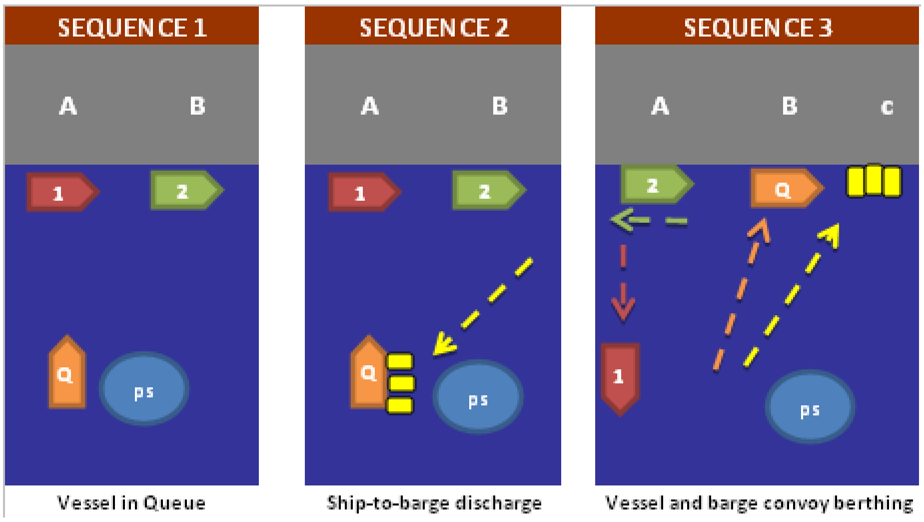

Diagram 15: Barge System operation and dynamics

*Barge convoys depicted in yellow.

** Upon arrival of queuing vessel to pilot’s station, a barge convoy is sent alongside the ship to discharge partial lots of cargo on a ship-to-barge operation. Once any berth is readily available, the vessel is directed to such position and the barge(s) are directed to their assigned berth for discharge. If the full quantity of cargo to be discharged at such port is unloaded onto barges prior to the release of any berths, the vessel will sail outbound, without proceeding to berth at all; yet, the barge(s) will be sailed back to the port for product storage or discharging.*
Elaboration of the Author.

8.2 Assumptions of the barge model

In order to implement the barge network into the original model and the corresponding simulations, a few assumptions were formulated in order to implement corresponding variables accordingly. Assumptions are based on the authors' personal and professional appreciations. A description of the same reads as follows:

1. Each barge has a capacity of 2,000 mt. Barges do not count with self propulsion, therefore convoys must be sent to each vessel, propelled by an aiding ship such as a tug boat.

2. Convoys are formed as per estimated cargo discharge needs. The intention of convoy formation is to be able to discharge the full amount required on to barges under one single operation. If only one barge is loaded at a time, precious time and resources will be wasted, by returning the barge to shore, discharging it and returning it alongside the vessel. Convoys allow for only one shore-ship and ship-shore movement of barges per vessel.

3. Convoys of barges will be sent to the vessels according to the estimated tonnage which will be unloaded. Such tonnage is calculated on the basis of the amount of time the vessel is expected to queue with respect to barge size.[39]

4. No additional barges will be added to a convoy, if less than half of the barge capacity (1,000mt) is required to load on same. If 2,900 mt are available for unloading during the queuing time, only one barge will be assigned to the ship; discharging only 2,000 mt. The remaining 900 mt will be discharged at the port. This condition is assumed on the basis that efficiency is not achieved by discharging small amounts of cargo onto barges.

5. Discharge capacity per convoy is of 2,000 mt per day. The assumption is based on the idea that one barge per convoy can be loaded every 24 hours.[40]

6. Ports are equipped with enough number of barges to serve all corresponding demand. No barge scarcity is ever present.

8.3 Application of the barge model to the simulation

In order to compare the results obtained from the original simulations with the results of the barge system solution, the abovementioned assumptions have been applied to the original data models. Such objective was reached by the insertion of the assumptions as well as to some additional variables.

[39] I.E.: If a vessel requires 3,600 mt. to be discharged onto barges, a convoy of 2 barges will be assembled and assigned to the ship.

[40] Technical details on the operation of the barge system will not be discussed in this research.

1. Vessel definition: a cell identifying if the corresponding vessel is a candidate for barge discharging indicates allows the model to identify which vessels could require the service.

2. Vessel expected queueing time: a cell identifying total expected vessel queueing time. This variable identifies the time frame in which the barge convoy operation would work under.

3. Total tonnage available for discharge: a cell identifying the total tonnage which could be discharged onto barges. This value is determined by the total expected queuing time with respect to vessel-to-barge discharge rate (2,000 mt per day).

4. Number of barges assigned: a cell identifying how many barges should be assigned to each vessel, according to the total tonnage available for discharge cell.

5. Real tons discharged: a cell identifying how many tons will be loaded onto barges, according to the above variables and the assumptions on barge assignment previously described.

6. Remaining tons on board: a cell identifying how many tons remain on board after the vessel-to-barge discharge operation is finished. Such tonnage corresponds to the amount which will be discharged at the port. It allows identifying how much time the vessel will spend at the berth(s) assigned by the port.

8.4 Operational results of the proposal

The application of the barge system to the models' original data returned interesting positive results. Under this approach, all of the indicators improved with the application of the barge network solution in all of the simulations created. Such results indicate that the proposal is in fact useful from an operational standpoint with respect to improve time savings and berth usage. See Appendices 7 & 8 for full summary of results. Outcomes for the Port of Santa Marta are slightly better than for the Port of Barranquilla. The reason relies on the fact that the usage of the slow berth in the first port is reduced in most cases by the application of the solution. In such way, the weighted average discharge rate of the port is increased. In the case of Barranquilla, although the usage of the secondary berth is reduced, average discharge rate is the same as the one for the dedicated berth, therefore, weighted average discharge rates remain barely unchanged.

It must be understood that percent change variations do not follow a standard pattern for results related to the Port of Santa Marta (Reference: Figure 17, Figure 20 & Figure 22).. The reason for this is that not all "barge candidate" cargo can be loaded on barges. In many cases, such cargo remains on board, as barges only have a maximum capacity of 2000 mt each. On the other hand, barges will only be loaded if at least 50.0% of its capacity can be loaded with grain. The impact on the above conditions is higher in some cases than in others generating different patterns per scenario.

This condition affects the berth usage weighted averages which in turn directly influence the queuing models' μ variable. As this variable is a component of the (P_n) indicators as well, this indicator is reflects the same patterns as well. As the berth usage weighted average variable does not change in a smooth pattern, the queueing model and probabilistic results for the port of Santa Marta return non pattern-like variations (See Figure 15).[41] This condition does not occur in the Port of Barranquilla, as the discharge rates for both berths are the same. In such way, weighted averages are not affected in an asymmetric manner as it does in Santa Marta.

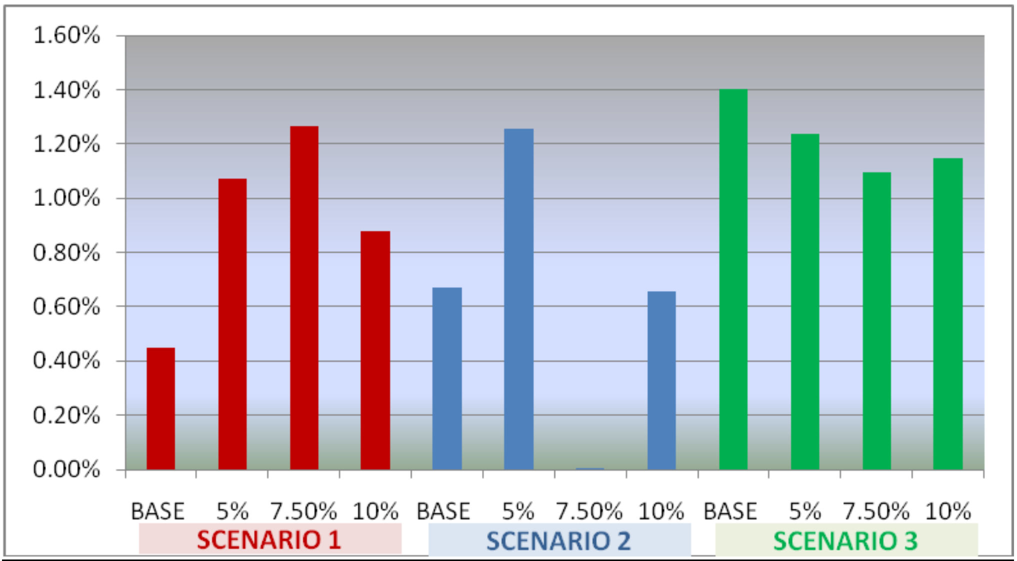

Figure 15: Cargo discharge weighted average change: Basic simulations vs. barge network application

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

The first indicator compared measures the percent change in total delay time for each port from the basic simulations with respect to the application of the barge network.. In the case of the Port of Santa Marta, interesting delay reductions were observed on each of the scenarios and simulations tested. Applying the barge network, the model shows time reductions ranging between 14.85% and 20.91% (See Figure 16). These results represent high significance in the fact that in cases in which agribulk cargo volumes are increased very highly, the barge network solution is an efficient short termed alternative to reduce the negative impact of that condition over the port.

[41] By comparing Figure 15 & Figure 22, it can be seen how the weighted average discharge rate percent change resembles the pattern followed by the (P_0). Therefore, this allows us to identify why the (P_0) percent change results follow a non-symmetrical pattern on the graph.

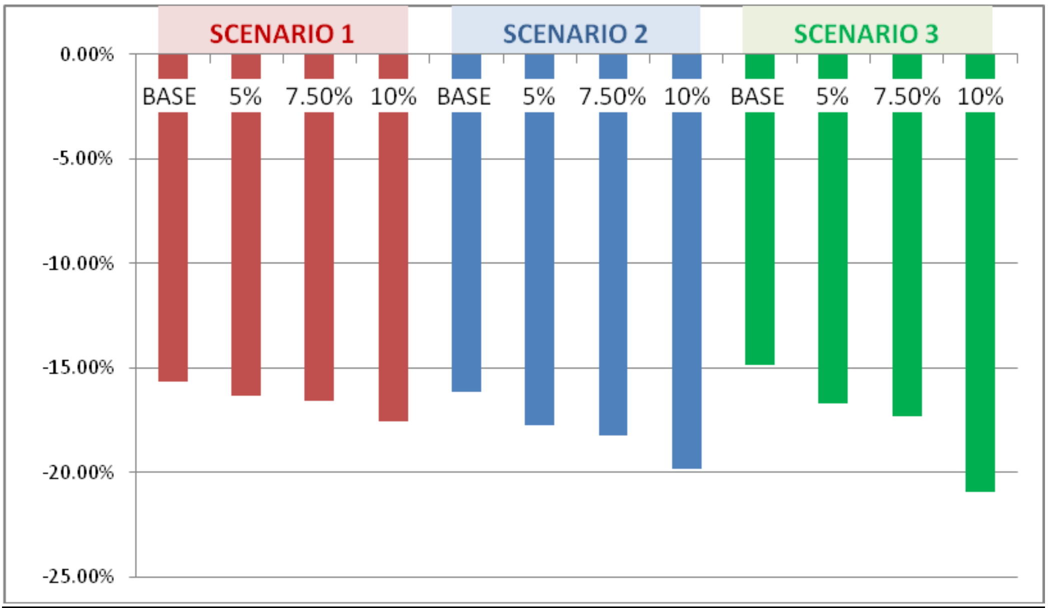

Figure 16: Total delay time reduction applying a barge network: Port Of Santa Marta

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

The second operational indicator worth analyzing to compare the proposed barge network performance is its impact on the total demurrage time specific to queueing events. These comparisons allow us to identify the real impact of the proposed barge network on the queue formations present along the year under study. Bearing in mind the fact that the network proposal is aimed on improving queueing conditions this is the value of highest importance with respect to the barge network proposed. Results for this comparative indicator are very positive and show high impact on the simulations corresponding to the Port of Santa Marta. Time delay in queueing events ranges between 20.16% and 26.85% on all of the simulations per scenario (See Figure 17). Such values, in which time reductions achieved, allow the network to be an interesting alternative to consider from an operational standpoint.

Being able to count with a tool which allows queues to decrease by at least 20.16% is a window to reduce demurrage costs, as well as to improve the desired vessel berthing pipeline flow. In real terms, the results above indicate that the barge network proposed can reduce queueing delay time at port by a total of at least sixteen days in the least congested cases. Overall, the results for this port are encouraging as the objective of using the dedicated berth as much as possible, is also improved, on top of the reduction of queueing times conditions.

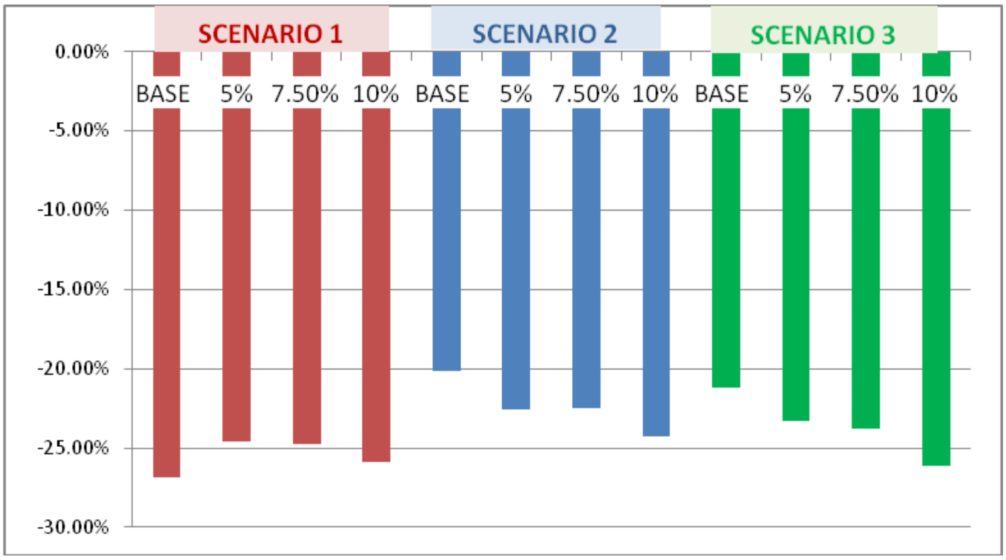

Figure 17: Total delay time reduction applying a barge network: specific to queueing events: Port Of Santa Marta

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

Results corresponding to the Port of Barranquilla, although positive for operational improvement purposes, are less significant than those of Santa Marta. Nevertheless, according to the simulation, delay time reductions of up to 6.64% can be achieved by using the proposed barge network on this port (See Figure 18). The result implies that in circumstances of high congestion or high cargo volumes, the barge network can be a valid alternative to lessen queues and vessel port times.

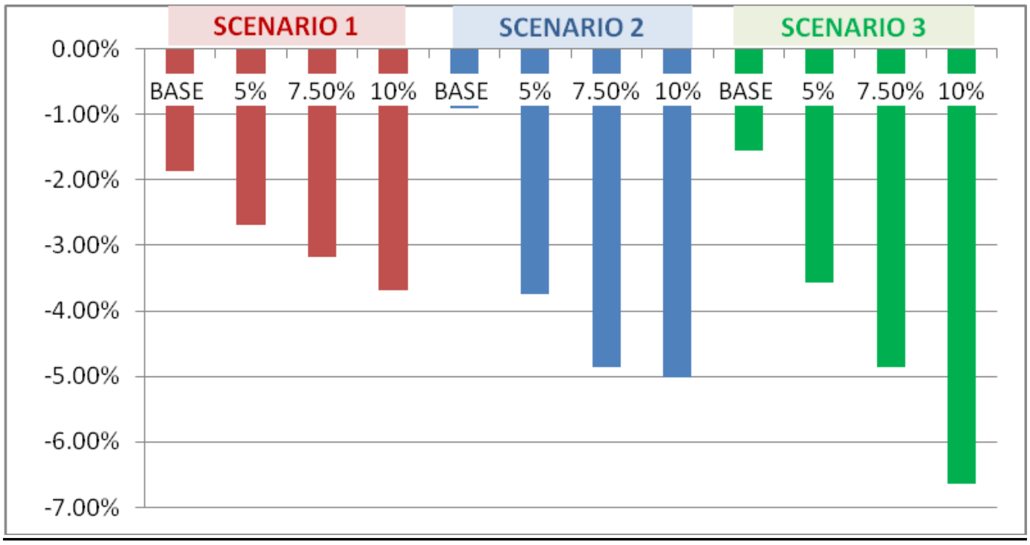

Figure 18: Total delay time reduction applying a barge network: Port Of Barranquilla

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

Results for this same port corresponding to delay reductions specific to queueing events returned interesting outcomes particularly to the simulations for cargo increases over the base of 7.5% and 10.0%. In these simulations, time delay reductions ranged between 7.36% and 14.63%. The results indicate that if cargo volume growth is high, the barge network can be useful to reduce the negative impact of queues over the operation. In real terms, the results above indicate that the barge network proposed can reduce queueing delay time at the port by more than six days in the most congested cases, according to the simulation over the period of time studied (See Figure 19).

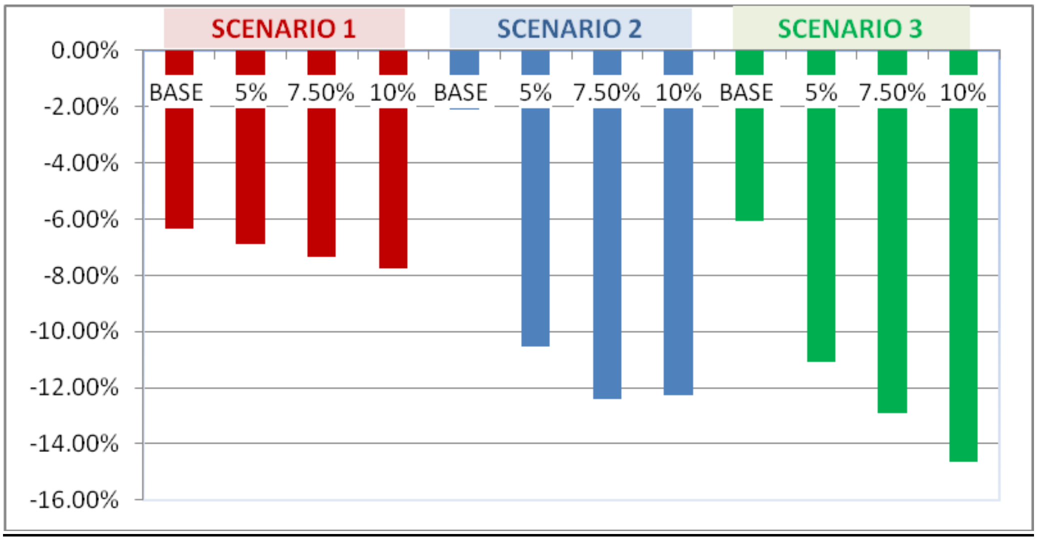

Figure 19: Total delay time reduction applying a barge network: specific to queueing events: Port Of Barranquilla

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

8.5 Queueing model data results for barge network

The application of the queueing model to the barge network solution and its corresponding comparison to the original data results returns similar outcomes to those viewed in the operational variables analysis. Positive time savings results and improved queuing conditions are the norm for both the ports of Santa Marta and Barranquilla. Again, results of the application of the barge network are better under this approach for Santa Marta.

Results for the Port of Santa Marta indicate that the average number of units in queue (Lq) and the average time a unit spends in queue (Wq)[42], are slightly reduced by aiding queuing scenarios with the barge network. Such indicators show reductions ranging between 1.58% and 4.72% at this port (See Figure 20).

[42] Percent variations in the Lq and Wq indicators are equal.

As previously explained, changes in the indicators mean that the conditions of the queue itself are improved by the solution presented. In the specific case of the Port of Santa Marta such results are relatively low under this approach.

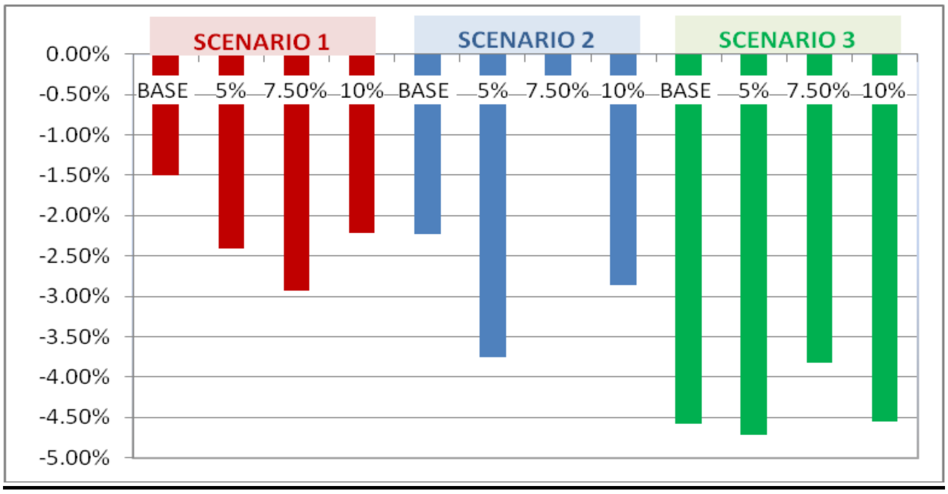

Figure 20: Average number of units in queue (Lq) reduction: Port of Santa Marta

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

Results corresponding to the port of Barranquilla follow the same pattern as the operational indicators did. Improvements are not as high as in Santa Marta, nevertheless significant and valuable. Average number of units in queue (Lq) and the average time a unit spends in queue (Wq) are reduced. In the case of this port, both of the indicators above are reduced in ranges between 6.12% and 9.76% amongst the different simulations conducted under each scenario (See Figure 21). Once again, it is important to mention that the relevance of this indicator stands on the reduction of the impact of delays on queueing vessels in terms of time and vessel flows at port.

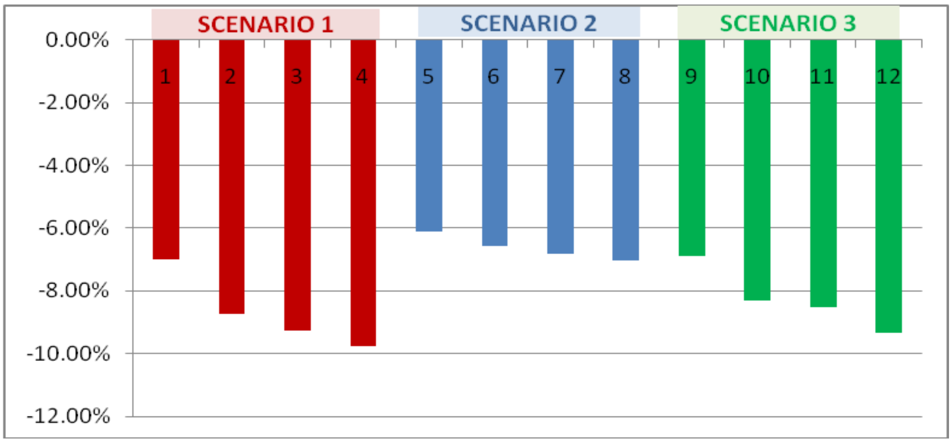

Figure 21: Average number of units in queue (Lq) reduction: Port of Barranquilla

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

8.6 Probabilistic results for barge network

Probabilistic results returned by the queueing model applied to the simulations corresponding to the barge network analysis are positive as well for the Port of Santa Marta. Perhaps the result which requires the highest attention is that which indicates the probability a vessel has of not finding any other vessel in the system or (P_0). As mentioned previously, a vessel entering an empty system, shall receive full resources and output from the port, equating into a faster vessel turnaround time. In that respect, the port in mention observes an increase in this indicator, in the range between 0.43% and 1.46% amongst all of the simulations conducted (See Figure 22).

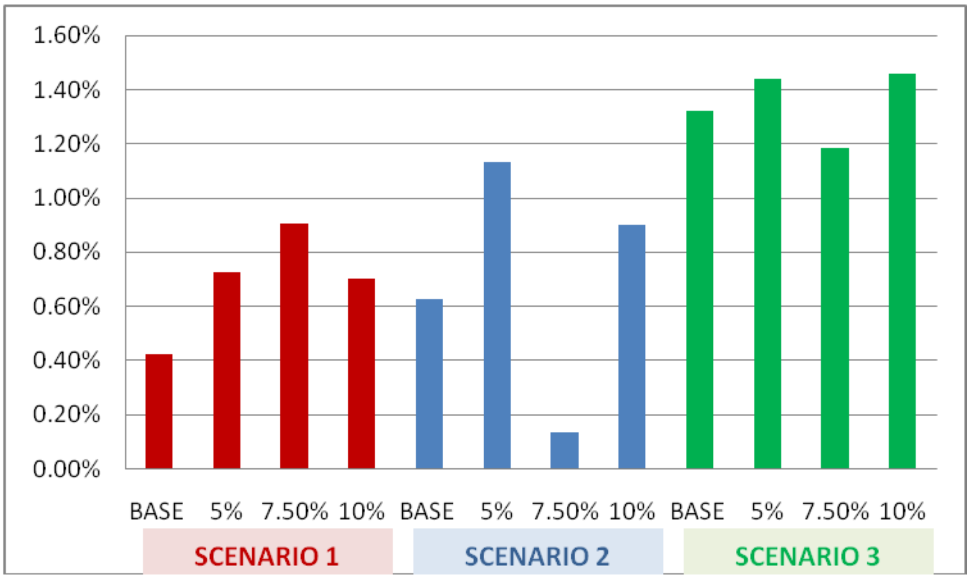

Figure 22: (P_0) indicator increase: Port of Santa Marta

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

Once again as expected from the results previously obtained, the Port of Barranquilla, will receive a lower (P_0) increase overall than Santa Marta. Nevertheless, the indicator shows improvement for all of the simulations in each of the three scenarios, in range between 1.75% and 3.16% (See Figure 23). The importance of the application of the barge network to queueing vessels for this particular port relies on the fact that improvement is visible particularly on high growth cargo volume levels. Such indication allows the author to infer that impacts of sudden peaks in volumes on the operation in mention could be easily be reduced by the usage of the barge network.

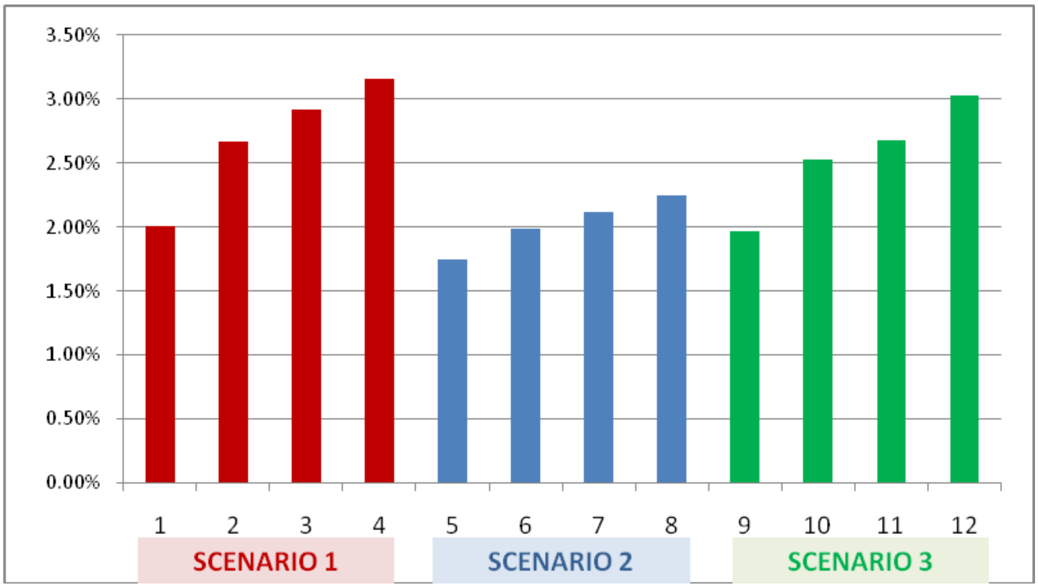

Figure 23: (P_0) indicator increase: Port of Barranquilla

* Source: Colombian Import Statistics Database: Naves S.A. & elaboration of the Author.

Chapter 9 Conclusions

Port congestion is one of the most critical bottlenecks in the supply chain of agribulk grains imported into Colombia. Time loss and delays caused by such condition, significantly impact the efficiency of the terminals, resulting in high levels of uncertainty for all of the participants in the chain. As port congestion builds up, controlling inventory volumes and orders becomes an activity based in improvisation, rather than a controlled and long term planned process.

In view of this situation, Port Authorities and terminal operators face very hard challenges, in order to maintain a steady pipeline type flow of incoming vessels into their premises. Disruptions in such pipeline, immediately affect costs, efficiency and the ports operational scheme itself. The result of the condition is the reduction in its attractiveness for users to handle cargo through that specific location, and a reduction in the regions' competitiveness. The impact of the port congestion on trade is compared to that created by quotas, duties and taxes. In view of the above, in order to achieve free trade, port congestion must be reduced as well.

The research undergone by the author, aimed at analyzing different congestion events and patterns of the three main Colombian ports located on the Caribbean coast, during 2008 returned interesting information. The available infrastructure for handling the imports of agribulk grain into these terminals appears to be insufficient to handle high seasons, where vessel inter-arrival rate is low. Nevertheless, the facilities appear to have relatively acceptable infrastructure to handle regular season arrivals.

From an operational standpoint, The Port of Cartagena (MEB) is by far the most prepared to handle not only high seasonality, but also steady cargo volume growth of all of the three locations. The results on time loss analysis, queue formation patterns and berth utilization, allow the author to conclude, that the port is up to standards and that not much further improvement is required in order to handle steady growth. On the other hand, however, the ports of Santa Marta and Barranquilla do require improvements in order to reduce time loss, queues and improve dedicated berth efficiency levels. Seasonal variations highly impact these two locations, resulting in queuing events which imply very high time loss indicators. On the other hand, the high reliance on secondary berths, results in discharging rate underperformance. The problem must be tackled by increasing discharge rates at the dedicated berths, in order to reduce intra-berth shifting. Also provide better infrastructure to the secondary berths to improve discharge rate as well in order to reduce queues and queue waiting times. The implementation of these recommendations will allow Santa Marta and Barranquilla to be able to cope with seasonality fluctuations and also to be prepared to cope with constant increase growth in arriving cargo volumes as well.

Although the ideal scenario is one in which no queues are formed and not delays are present, the efficient decision is described in the following statement: "If it costs more to build a facility with a larger service rate, an efficiently designed system will always cause some delays, because there is no benefit associated with any excess capacity which is never used. The benefit associated with any increment of capacity that is used for only a short period of time or infrequently is also very small.

Consequently the capacity should always be somewhat less than the maximum demand during some time period (Newell, 1982)."

From a theoretical standpoint, based on the results obtained from the **M/M/2** queueing model used, similar results were observed by the author. The Port of Cartagena (MEB), has very impressive results in terms of average number units in queue as well as in average time of vessels in queue. Such indicators are very low, and only return averages of few hours each. Results regarding the probabilities of having none, 1, 2 or 3 vessels in the system are interpreted by the author as indicating very low odds for a vessel to find other ships discharging at the port upon its arrival. In such way, likelihood of queue formation at Cartagena is extremely low.

Results for the Ports of Santa Marta and Barranquilla are not as positive from the M/M/2 model results standpoint. However, the information obtained from the model indicates that the situation of these two ports is less critical as the operational results indicate. The reason being is that the model takes into consideration averages for every single day, therefore whenever no vessels are present, averages of the model decrease substantially. However, the results are useful as a comparative tool not only between ports but also, among different scenarios within a same port.

From the queueing model, the author concludes that likelihood of time wasting and delays at the Port of Barranquilla are relative and that queue formations are likely to happen in about 20.0% of the cases. A very similar result appears to occur for the port of Santa Marta. In terms of time wasting at queue or the amount of units in queue is still low, indicating, the flow of the vessels through a congested system should be relatively fast. Room for improvement in queue handling schemes is broadly available.

Results corresponding to the application of the barge network presented by the author, are positive and worth reviewing in depth. In this matter, the operational results were the most outstanding, and significant time loss reduction was achieved, by allowing queueing vessels to reduce the total cargo to be discharged at berth. The barge network serves as a short term solution which can aid port operations during high seasons. It is clear that the network is much more efficient in ports with higher and more frequent congestion and queueing patterns as in Santa Marta. Nevertheless, it can be a useful alternative, in ports with less congestion events although with sudden heavy increases of dry bulk cargo reception as Barranquilla.

Future research on congestion and the application of queueing theory on these three ports is possible. Important attention must be given to improving the condition of queues, not through the simple proposal of increasing number of berths dedicated to the agribulk discharge process; as such solution is expensive and not likely to happen. A proper approach should be to investigate how the berthing patterns can be changed and improved in order to view faster vessel flow through the system. Furthermore, alternate solutions aimed at the study of improving queueing formations handling is a topic with a lot of material to be analyzed. Proposing solutions which allow the reduction of queueing times will be material of great assistance to the improvement of these ports agribulk discharging operations.

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Apendices

Appendix 1: Berth specific discharge rate calculation table – Port of Santa Marta

PORT OF SANTA MARTA		
Product	**Total**	**Dis-rate avg. / day**
BAKERY MEAL	13,097.78	3,000.00
COOKIE MEAL	1,447.64	3,000.00
D.D.G.S.	14,688.06	3,000.00
GLUTEN CORN	41,231.23	3,000.00
H.R.W WHEAT	45,162.01	6,000.00
SORGHUM	9,809.24	6,000.00
SOYBEAN MEAL	219,897.23	3,000.00
SOYBEANS	69,040.58	6,000.00
WHEAT IN BULK	184,750.94	6,000.00
WHITE CORN	21,573.96	6,000.00
YELLOW CORN	831,720.38	6,000.00
Grand Total	**1,452,419.03**	
	AVERAGED TOTAL	**5,400.25**

** Source: Colombian Import Statistics Database: Naves S.A.*

Appendix 2: Berth specific discharge rate calculation table – Port of Barranquilla

PORT OF BARRANQUILLA		
Product	**Total Tons**	**Dis-rate avg. per day**
BAKERY MEAL	2,513.85	3,000.00
D.D.G.S.	5,866.06	3,000.00
GLUTEN CORN	61,956.24	3,000.00
H. R.W. WHEAT	103,431.85	5,800.00
POLLOMIX	3,000.00	3,000.00
S. R.W. WHEAT	5,020.38	5,800.00
SORGHUM	5,050.00	5,800.00
SOYBEAN MEAL	219,967.05	3,000.00
SOYBEANS	21,920.24	5,800.00
SUNFLOWER PELLETS	4,070.00	5,800.00
WHEAT IN BULK	216,264.77	5,800.00
WHITE CORN	63,904.06	5,800.00
YELLOW CORN	799,443.61	5,800.00
YELLOW SOYAS	482.53	5,800.00
Grand Total	**1,512,890.64**	
	DISRATE AVG / DAY	**5,257.17**

** Source: Colombian Import Statistics Database: Naves S.A.*

Appendix 3: Berth specific discharge rate calculation table – Port of Cartagena (MEB)

PORT OF CARTAGENA (MEB)		
Product	**Total**	**Dis-rate avg. per day**
D.D.G.S.	21,974.69	3,000.00
GLUTEN CORN	18,616.77	3,000.00
H.R.W. WHEAT	43,575.83	6,000.00
S.R.W. WHEAT	4,936.77	6,000.00
SORGHUM	9,809.23	6,000.00
SOYBEAN MEAL	18,396.88	6,000.00
WHEAT IN BULK	34,617.79	6,000.00
YELLOW CORN	286,963.42	6,000.00
Grand Total	**438,891.37**	
	DISRATE AVG	**5,722.54**

** Source: Colombian Import Statistics Database: Naves S.A.*

Appendix 4: Basic Data Simulations' operational & theoretical models results – Port of Santa Marta

	SCENARIO 1				SCENARIO 2				SCENARIO 3			
VARIABLE	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%
DISCHARGE WEIGHTED AVG. IN MT (2008)	5,168.72	5,155.06	5,147.52	5,158.62	5,184.20	5,160.83	5,204.43	5,175.49	5,151.26	5,150.06	5,164.64	5,153.85
TOTAL DELAY TIME (IN DAYS)	(81.54)	(86.80)	(89.05)	(91.76)	(97.46)	(102.68)	(105.99)	(110.25)	(89.36)	(97.98)	(103.58)	(111.97)
TOTAL VESSELS WHICH QUEUED	17.00	17.00	17.00	18.00	28.00	29.00	30.00	35.00	23.00	25.00	30.00	30.00
TOTAL DELAY IN QUEUING	(52.48)	(56.69)	(58.62)	(61.37)	(76.78)	(81.79)	(86.26)	(91.13)	(60.58)	(69.32)	(76.55)	(84.53)
TOTAL TIME USED FOR DISCHARGE (DAYS)	348.55	367.16	376.09	385.47	364.47	383.04	393.03	403.96	356.37	378.34	390.62	405.69
REAL TONS DISCHARGED / DAY	4,167.04	3,955.81	3,861.87	3,767.90	3,984.99	3,791.81	3,695.45	3,595.45	4,075.59	3,838.91	3,718.22	3,580.16
TOTAL SHIFTING EVENTS	25.00	26.00	25.00	26.00	25.00	27.00	26.00	26.00	23.00	24.00	21.00	22.00
% OF VESSELS QUEUEING FROM TOTAL	21.25%	21.25%	21.25%	22.50%	35.00%	36.25%	37.50%	43.75%	28.75%	31.25%	37.50%	37.50%
TOTAL # OF VESSEL ARRIVALS (x)	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
MEAN # ARRIVALS OF VESSEL / DAY (λ)	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
MEAN SERVICE TIME / VESSEL IN DAYS (μ)	0.27	0.26	0.25	0.25	0.28	0.26	0.26	0.25	0.27	0.26	0.26	0.25
AVG. TIME BETWEEN ARRIVALS IN DAYS (1/λ)	4.56	4.51	4.45	4.40	4.35	4.29	4.24	4.20	4.15	4.10	4.06	4.01
MEAN BERTH SERVICE RATE (SHIPS / DAY) (1/μ)	3.64	3.83	3.93	4.01	3.63	3.82	3.88	4.00	3.65	3.83	3.91	4.01
AVG. # OF UNITS IN QUEUE (Lq)	0.15	0.19	0.21	0.24	0.18	0.22	0.25	0.28	0.21	0.26	0.29	0.33
AVG. # OF UNITS IN THE SYSTEM (L)	0.95	1.04	1.09	1.15	1.01	1.11	1.16	1.23	1.09	1.20	1.26	1.33
AVG. TIME A UNIT SPENDS IN QUEUE (Wq)	0.69	0.84	0.95	1.05	0.76	0.95	1.06	1.17	0.88	1.07	1.19	1.34
AVG. TIME A UNITSPENDS IN THE SYSTEM (W)	4.32	4.67	4.87	5.06	4.39	4.77	4.94	5.17	4.52	4.90	5.10	5.35
(P0)	43.00%	40.37%	38.79%	37.39%	41.12%	38.38%	38.38%	35.49%	38.90%	36.31%	34.92%	33.32%
(P1)	34.28%	34.30%	34.22%	34.08%	34.31%	34.18%	34.18%	33.79%	34.22%	33.93%	33.69%	33.33%
(P2)	13.66%	14.57%	15.09%	15.53%	14.32%	15.22%	15.22%	16.09%	15.06%	15.85%	16.25%	16.67%
(P3)	5.45%	6.19%	6.65%	7.08%	5.97%	6.78%	6.78%	7.66%	6.62%	7.41%	7.84%	8.34%

** Source: Colombian Import Statistics Database: Naves S.A.*

<u>Appendix 5: Basic Data Simulations' operational & theoretical models results – Port of Barranquilla</u>

	SCENARIO 1				SCENARIO 2				SCENARIO 3			
VARIABLE	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%
DISCHARGE WEIGHTED AVG. IN MT (2008)	5,257.17	5,257.17	5,257.17	5,257.17	5,257.17	5,257.17	5,257.17	5,257.17	5,257.17	5,257.17	5,257.17	5,257.17
TOTAL DELAY TIME (IN DAYS)	(55.32)	(60.37)	(62.37)	(65.44)	(46.69)	(50.42)	(51.93)	(53.52)	(53.09)	(58.87)	(61.18)	(66.23)
TOTAL VESSELS WHICH QUEUED	17.00	20.00	21.00	22.00	14.00	16.00	18.00	18.00	16.00	21.00	21.00	23.00
TOTAL DELAY IN QUEUING	(27.32)	(33.77)	(36.47)	(40.24)	(20.09)	(24.52)	(26.03)	(27.62)	(25.09)	(31.57)	(33.88)	(39.63)
TOTAL TIME USED FOR DISCHARGE (DAYS)	343.10	362.53	371.73	381.99	334.46	352.59	361.29	370.07	340.87	361.04	370.54	382.78
REAL TONS DISCHARGED / DAY	4,409.48	4,381.77	4,375.15	4,356.60	4,523.32	4,290.83	4,187.50	4,088.11	4,438.32	4,190.42	4,082.95	3,952.34
% OF VESSELS QUEUEING FROM TOTAL	18.09%	21.28%	22.34%	23.40%	14.89%	17.02%	19.15%	19.15%	17.02%	22.34%	22.34%	24.47%
TOTAL # OF VESSEL ARRIVALS (x)	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00	94.00
MEAN # ARRIVALS OF VESSEL / DAY (λ)	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
MEAN SERVICE TIME / VESSEL IN DAYS (μ)	0.33	0.31	0.30	0.30	0.33	0.31	0.30	0.30	0.33	0.31	0.30	0.30
AVG. TIME BETWEEN ARRIVALS IN DAYS (1/λ)	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88
MEAN BERTH SERVICE RATE (SHIPS / DAY) (1/μ)	3.06	3.21	3.29	3.37	3.06	3.21	3.29	3.37	3.06	3.21	3.29	3.37
AVG. # OF UNITS IN QUEUE (Lq)	0.15	0.17	0.19	0.20	0.15	0.17	0.19	0.20	0.15	0.17	0.19	0.20
AVG. # OF UNITS IN THE SYSTEM (L)	0.93	1.00	1.03	1.07	0.93	1.00	1.03	1.07	0.93	1.00	1.03	1.07
AVG. TIME A UNIT SPENDS IN QUEUE (Wq)	0.56	0.66	0.72	0.78	0.56	0.66	0.72	0.78	0.56	0.66	0.72	0.78
AVG. TIME A UNITSPENDS IN THE SYSTEM (W)	3.62	3.88	4.01	4.15	3.62	3.88	4.01	4.15	3.62	3.88	4.01	4.15
(P0)	43.45%	41.45%	40.47%	39.51%	43.45%	41.5%	40.47%	39.51%	43.45%	41.45%	40.47%	39.51%
(P1)	34.26%	34.31%	34.30%	34.26%	34.26%	34.3%	34.30%	34.26%	34.26%	34.31%	34.30%	34.26%
(P2)	13.50%	14.20%	6.16%	14.86%	13.50%	14.2%	14.54%	14.86%	13.50%	14.20%	14.54%	14.86%
(P3)	5.32%	5.88%	2.61%	6.44%	5.32%	5.9%	6.16%	6.44%	5.32%	5.88%	6.16%	6.44%

** Source: Colombian Import Statistics Database: Naves S.A.*

Appendix 6: Basic Data Simulations' operational & theoretical models results – Port of Cartagena (MEB)

	SCENARIO 1				SCENARIO 2				SCENARIO 3			
VARIABLE	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%
DISCHARGE WEIGHTED AVG. IN MT	5,568.86	5,564.32	5,722.54	5,722.54	5,605.27	5,599.27	5,594.12	5,588.97	5,646.38	5,633.88	5,629.19	5,622.79
TOTAL DELAY (DAYS)	-18.67	-19.57	-19.88	-20.19	-15.92	-16.36	-16.63	-16.91	-22.55	-23.68	-23.94	-24.5
TOTAL VESSELS QUEUEING	4	5	5	5	5	5	5	5	6	6	6	6
TOTAL DELAY IN QUEUING	3.25	4.06	4.29	4.52	4.61	4.93	5.1	5.26	6.91	8.03	8.31	8.68
TOTAL TIME USED FOR DISCHARGE (DAYS)	95.37	100.1	102.32	104.56	92.62	96.89	99.08	101.27	99.24	104.21	106.39	108.87
REAL TONS DISCHARGED / DAY	191.75	182.69	178.72	174.9	197.45	188.75	184.57	180.58	184.27	175.49	171.89	167.98
TOTAL SHIFTING EVENTS	6	6	6	6	6	7	7	7	5	5	5	6
% OF VESSELS QUEUEING FROM TOTAL	11.11%	13.89%	13.89%	13.89%	13.89%	13.89%	13.89%	13.89%	16.67%	16.67%	16.67%	16.67%
TOTAL # OF VESSEL ARRIVALS IN 2008 (x)	36	36	36	36	36	36	36	36	36	36	36	36
MEAN # ARRIVALS OF VESSEL / DAY IN 2008 (λ)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MEAN SERVICE TIME / VESSEL IN 2008 IN DAYS (μ)	0.46	0.43	0.44	0.43	0.46	0.44	0.43	0.42	0.46	0.44	0.43	0.42
AVG. TIME BETWEEN ARRIVALS IN DAYS (1/ λ)	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14
MEAN BERTH SERVICE RATE (SHIPS / DAY) (1/μ)	2.19	2.3	2.29	2.34	2.17	2.29	2.34	2.4	2.16	2.27	2.33	2.39
AVG. # OF UNITS IN QUEUE (Lq)	0	0	0	0	0	0	0	0	0	0	0	0
AVG. # OF UNITS IN THE SYSTEM (L)	0.22	0.23	0.23	0.23	0.22	0.23	0.23	0.24	0.22	0.23	0.23	0.24
AVG. TIME A UNIT SPENDS IN QUEUE (Wq)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03
AVG. TIME A UNITSPENDS IN THE SYSTEM (W)	2.22	2.33	2.32	2.38	2.2	2.32	2.37	2.43	2.18	2.3	2.36	2.42
AVG. OVERTIME FOR 2008 (IN DAYS)	0.03	0.03	0.03	-0.07	0.03	0.03	0.03	-0.07	0.02	0.03	0.03	-0.07
(P_0)	80.63%	79.62%	79.70%	79.28%	80.63%	79.74%	79.29%	78.84%	80.75%	79.85%	79.40%	78.95%
(P_1)	9.23%	9.76%	9.72%	9.94%	9.23%	9.70%	9.94%	10.18%	9.16%	9.64%	9.88%	10.12%
(P_2)	0.99%	1.11%	1.10%	1.15%	0.99%	1.09%	1.15%	1.20%	0.98%	1.08%	1.13%	1.19%
(P_3)	0.11%	0.13%	0.12%	0.13%	0.11%	0.12%	0.13%	0.14%	0.10%	0.12%	0.13%	0.14%

** Source: Colombian Import Statistics Database: Naves S.A.*

<u>Appendix 7: Barge Network Simulations' operational & theoretical models results – Port of Santa Marta</u>

VARIABLE	SCENARIO 1				SCENARIO 2				SCENARIO 3			
	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%
DISCHARGE WEIGHTED AVERAGE IN MT (YEAR ROUND)	0.45%	1.07%	1.27%	0.88%	0.67%	1.26%	0.00%	0.66%	1.40%	1.24%	1.10%	1.15%
TOTAL DELAY TIME (IN DAYS)	-15.64%	-16.32%	-16.56%	-17.58%	-16.12%	-17.73%	-18.24%	-19.86%	-14.85%	-16.70%	-17.34%	-20.91%
TOTAL VESSELS WHICH QUEUED IN 2008	-5.88%	0.00%	0.00%	0.00%	0.00%	-3.45%	0.00%	-8.57%	0.00%	0.00%	-6.67%	-3.33%
TOTAL DEMURRAGE CAUSED IN QUEUING EVENTS	-26.85%	-24.60%	-24.74%	-25.87%	-20.16%	-22.54%	-22.48%	-24.30%	-21.23%	-23.26%	-23.79%	-26.15%
TOTAL TIME USED FOR DISCHARGE (DAYS)	-3.66%	-3.86%	-3.92%	-4.18%	-4.31%	-4.75%	-4.92%	-5.42%	-3.72%	-4.32%	-4.60%	-5.77%
REAL TONS DISCHARGED PER DAY	3.80%	4.01%	4.08%	4.37%	4.50%	4.99%	5.17%	5.73%	3.87%	4.52%	4.82%	6.13%
REAL TONS DISCHARGED PER HOUR	3.80%	4.01%	4.08%	4.37%	4.50%	4.99%	5.17%	5.73%	3.87%	4.52%	4.82%	6.13%
TOTAL SHIFTING EVENTS	0.00%	0.00%	4.00%	0.00%	-4.00%	0.00%	-3.85%	-3.85%	0.00%	0.00%	0.00%	-4.55%
% OF VESSELS QUEUEING FROM TOTAL	-5.88%	0.00%	0.00%	0.00%	0.00%	-3.45%	0.00%	-8.57%	0.00%	0.00%	-6.67%	-3.33%
TOTAL NUMBER OF VESSEL ARRIVALS IN 2008 (*x*)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MEAN NUMBER ARRIVALS OF VESSEL / DAY IN 2008 (λ)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MEAN SERVICE TIME PER VESSEL IN 2008 IN DAYS (μ)	0.45%	0.72%	0.86%	0.65%	0.67%	1.12%	0.13%	0.84%	1.40%	1.42%	1.14%	1.35%
AVERAGE TIME BETWEEN ARRIVALS IN DAYS (1/λ)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MEAN BERTH SERVICE RATE IN 2008 IN (SHIPS PER DAY) (1/μ)	-0.45%	-0.71%	-0.86%	-0.64%	-0.66%	-1.11%	-0.13%	-0.83%	-1.38%	-1.40%	-1.12%	-1.33%
AVERAGE NUMBER OF UNITS IN QUEUE (Lq)	-1.50%	-2.41%	-2.92%	-2.21%	-2.22%	-3.75%	-0.44%	-2.85%	-4.58%	-4.72%	-3.82%	-4.55%
AVERAGE NUMER OF UNITS IN THE SYSTEM (L)	-0.62%	-1.01%	-1.24%	-0.95%	-0.91%	-1.58%	-0.19%	-1.22%	-1.89%	-1.99%	-1.62%	-1.95%
AVERAGE TIME A UNIT SPENDS IN QUEUE (Wq)	-1.50%	-2.41%	-2.92%	-2.21%	-2.22%	-3.75%	-0.44%	-2.85%	-4.58%	-4.72%	-3.82%	-4.55%
AVERAGE TIME A UNITSPENDS IN THE SYSTEM (W)	-0.62%	-1.01%	-1.24%	-0.95%	-0.91%	-1.58%	-0.19%	-1.22%	-1.89%	-1.99%	-1.62%	-1.95%
(P0)	0.43%	0.73%	0.91%	0.70%	0.63%	1.13%	0.13%	0.90%	1.32%	1.44%	1.19%	1.46%
(P1)	-0.02%	0.01%	0.04%	0.05%	-0.04%	0.01%	0.00%	0.06%	-0.08%	0.01%	0.05%	0.11%
(P2)	-0.47%	-0.70%	-0.81%	-0.59%	-0.70%	-1.10%	-0.12%	-0.77%	-1.46%	-1.39%	-1.08%	-1.23%
(P3)	-0.92%	-1.41%	-1.66%	-1.23%	-1.36%	-2.20%	-0.25%	-1.59%	-2.82%	-2.77%	-2.19%	-2.54%

** Source: Colombian Import Statistics Database: Naves S.A.*

Appendix 8: Barge Network Simulations' operational & theoretical models results - Port of Barranquilla

	SCENARIO 1				SCENARIO 2				SCENARIO 3			
VARIABLE	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%	BASE	BS + 5%	BS + 7.5%	BS + 10%
DISCHARGE WEIGHTED AVERAGE IN MT (YEAR ROUND)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
AVERAGE DISCHARGE TIME AVAILABLE	0.00%	0.00%	0.00%	0.00%	0.00%	-4.76%	-6.98%	-9.09%	0.00%	-4.76%	-6.98%	-9.09%
AVERAGE DISCHARGE SLACK	0.00%	0.00%	0.00%	0.00%	0.00%	24.05%	41.00%	63.32%	0.00%	24.05%	41.00%	63.32%
TOTAL DEMURRAGE TIME (IN DAYS)	-1.87%	-2.69%	-3.18%	-3.69%	-0.90%	-3.74%	-4.86%	-5.02%	-1.56%	-3.57%	-4.85%	-6.64%
TOTAL VESSELS WHICH QUEUED IN 2008	-5.88%	-10.00%	-9.52%	-9.09%	0.00%	-6.25%	-11.11%	-11.11%	-6.25%	-19.05%	-14.29%	-8.70%
TOTAL DEMURRAGE CAUSED IN QUEUING EVENTS	-6.35%	-6.88%	-7.36%	-7.74%	-2.09%	-10.54%	-12.39%	-12.27%	-6.08%	-11.09%	-12.90%	-14.63%
TOTAL TIME USED FOR DISCHARGE (DAYS)	-2.10%	-2.66%	-2.86%	-3.06%	-1.73%	-2.23%	-2.44%	-2.52%	-2.01%	-2.69%	-2.95%	-3.47%
REAL TONS DISCHARGED PER DAY	2.14%	2.73%	2.95%	3.16%	1.76%	2.28%	2.50%	2.58%	2.06%	2.76%	3.04%	3.60%
REAL TONS DISCHARGED PER HOUR	2.14%	2.73%	2.95%	3.16%	1.76%	2.28%	2.50%	2.58%	2.06%	2.76%	3.04%	3.60%
TOTAL NUMBER OF VESSEL ARRIVALS IN 2008 (*x*)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MEAN NUMBER ARRIVALS OF VESSEL / DAY IN 2008 (λ)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MEAN SERVICE TIME PER VESSEL IN 2008 IN DAYS (µ)	2.19%	2.72%	2.88%	3.02%	1.90%	2.02%	2.08%	2.14%	2.14%	2.58%	2.64%	2.89%
AVERAGE TIME BETWEEN ARRIVALS IN DAYS (1/λ)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MEAN BERTH SERVICE RATE IN 2008 IN (SHIPS PER DAY) (1/µ)	-2.14%	-2.65%	-2.80%	-2.94%	-1.86%	-1.98%	-2.04%	-2.09%	-2.10%	-2.51%	-2.57%	-2.81%
AVERAGE NUMBER OF UNITS IN QUEUE (Lq)	-7.00%	-8.73%	-9.26%	-9.76%	-6.12%	-6.58%	-6.81%	-7.05%	-6.88%	-8.29%	-8.53%	-9.35%
AVERAGE NUMER OF UNITS IN THE SYSTEM (L)	-2.89%	-3.69%	-3.96%	-4.22%	-2.53%	-2.77%	-2.89%	-3.03%	-2.84%	-3.50%	-3.64%	-4.04%
AVERAGE TIME A UNIT SPENDS IN QUEUE (Wq)	-7.00%	-8.73%	-9.26%	-9.76%	-6.12%	-6.58%	-6.81%	-7.05%	-6.88%	-8.29%	-8.53%	-9.35%
AVERAGE TIME A UNITSPENDS IN THE SYSTEM (W)	-2.89%	-3.69%	-3.96%	-4.22%	-2.53%	-2.77%	-2.89%	-3.03%	-2.84%	-3.50%	-3.64%	-4.04%
(P0)	2.01%	2.67%	2.92%	3.16%	1.75%	1.99%	2.12%	2.25%	1.97%	2.53%	2.67%	3.02%
(P1)	-0.17%	-0.05%	0.04%	0.14%	-0.15%	-0.03%	0.04%	0.11%	-0.17%	-0.05%	0.04%	0.13%
(P2)	-2.31%	-2.70%	-5.49%	-2.80%	-2.01%	-2.01%	-2.00%	-1.99%	-2.26%	-2.56%	-2.53%	-2.68%
(P3)	-4.40%	-5.28%	-8.13%	-5.66%	-3.83%	-3.95%	-4.00%	-4.04%	-4.32%	-5.01%	-5.04%	-5.41%

** Source: Colombian Import Statistics Database: Naves S.A.*