

Modeling and Simulation of Berthing Processes for a Panamanian Container Terminal using BPMN and Discrete Event Simulation

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Abstract

This study presents the development of a decision support tool for a container terminal in Panama, located at the Pacific entrance of the Panama Canal. The rapid growth of containerized cargo movement in international terminals in the country has also increased the complexity in strategic and tactical decision making, affecting operational decisions as well. Therefore, the Business Process Modeling methodology is proposed as a tool to support the identification and visualization of the processes associated with container ships and participants in this process, followed by a discrete event simulation that generates the main performance indicators for this process area. The current model or "As is" model can result in "to be" or optimization models.

Keywords

Container terminal, BPMN, discrete event, modeling and simulation, port logistics.

1. Introduction

Seaborne trade is directly influenced by driving forces like demand trade patterns and competition that affect its global development. Variations in demand and the rise of new competition are some of the main factors that create an uncertain environment for strategic, tactical and operations decision making. Moreover, strategic and tactical decisions tend to be capital intensive and must be flexible to adapt and expand in terms of infrastructure and technological changes in the long run (Stopford, 2008).

This study presents the development of a decision support tool for a container terminal in Panama, located at the Pacific entrance of the Panama Canal. The rapid growth of containerized cargo movement in international terminals in the country has also increased the complexity in strategic and tactical decision making, affecting operational decisions as well. Therefore, the Business Process Modeling methodology is proposed as a tool to support the identification and visualization of the processes associated with container ships and participants in this process, followed by a discrete event simulation that generates the main performance indicators for this process area. From the current model or "As is" model, an improved or optimized model, a "to be" model can be created.

Standardized graphical notation BPMN (Business Process Modeling Notation) is a graphical representation for the identification, visualization and graphic processes design of business process models. The advantage of developing a model is that it helps us to shape our understanding of a subject, so it can be communicated and validated by experts, and, allows us to analyze the process under study, to explore alternatives without interfering with the real system (Sharp & McDermott, 2011). BPMN version 2.0 is created by IBM based on Business Process Diagrams (BPD) containing standardized and defined elements. This allows us to model complex business processes, in an easy way to be understood by non-technical users. In addition, helps to represent complex business processes models, to be easily translated into execution languages (Owen & Raj, 2003).

Process modeling is a good exercise prior to any initiative of process optimization or automation in container terminals. Finding the root of the problem provides an overview of the main causes that affect the process negatively, factors that make it become less productive or inefficient (Elmoufti, 2012). Besides optimizing, the trend in international container terminals is towards certification of the terminal's services. For example the certification of "Container Terminal Quality Indicator" (CTQIs), is an initiative implemented by terminals in the Region such as in Colombia. In both cases, business process modeling is helpful to the materialization of strategic objectives of any firm towards real and measurable performance indicators.

Container terminals around the world have implemented various methodologies for decision making in conjunction with business process diagrams and analytical models like operations research, simulation, emulation, and Lean Six Sigma, among others. However, these implementations cannot be directly applied to the terminal under consideration prior to a holistic analysis of exogenous variables (local and regional demand trade patterns, economic activity, etc.), and endogenous variables (resources, service configuration, intra-terminal logistics' behavior) that directly modifies the context in study.

When developing a project for marine terminals it is important to address the specific characteristics of such terminal, and consider specific properties of the terminal environments (Saanen & Waal, 2004). Some of these aspects are the mix of its operating systems, cultural context, regulations and operational policies, among others. Even in the same country it can be port terminals dedicated to two different market segments, as in the case of container terminals in the Pacific and Caribbean coasts of Panama. Particularly, in Port of Balboa, the influence of sharing the inner navigation channel and anchorage area with the Panama Canal is identified in the first stage of the proposed process model and simulation of this project.

Although, modeling and simulation have been used in the last decades in port terminals, it is a complex and difficult task to ensure the proper usage of them, because of the level of specialized human resource for such kind of projects (Shetty et al., 2012). For the reasons aforementioned, the following research question is stated: How to clearly identify the processes associated to the containership loading/unloading operations, since its arrival to its departure the case study terminal, to ease decision-making? Besides the development of the BP Model for Berthing Processes, a discrete event simulation is also proposed for the model validation. Categorization by vessels "types" according to their contribution in throughput (containers) per call, arrival frequencies and structural characteristics is performed. A survey of available infrastructure and superstructure in the period in study (third quarter, 2012) is also made. Other aspects such as handled TEUs in a long run period, average time in port per call and ship type, time in the system and operating times of the vessel, as well as inter-arrival times and waiting times, were considered for the construction of the main performance indicators for this service area. Other performance indicators, as overall berth productivity, quay cranes and vessels gross productivities are obtained.

The proposed methodology in this study has been used to obtain the first simulation of berthing processes at the Pacific entrance of the Panama Canal, being able to generate container ship arrivals in a year of simulation for the case study terminal, generated by probability distributions from historic data. From the model, it is possible to measure the main key performance indicators mentioned above, standardized in 1987 by UNCTAD, cited by

(CEPAL, UN, 2006) and evaluated in the last newsletter indicators for terminals worldwide by the Journal of Commerce in its last publication (PIERS - JOC, 2013).

This project has been also a guide for standardization in modeling business process languages in the terminal of study, as well as in its sister terminal operating at the Caribbean entrance of the Panama Canal. Both terminals have a direct land connection through the Panama Canal Railway trains. It has generated three research projects at the level of "task models" between the terminal and the International Maritime University of Panama (first quarter 2014). Projects that have contributed as a source of information for the new department in processes quality as well as an input for the virtual intranet library created for decision makers to have access to generated maps in the enterprise. Along with these projects, this research has been used to conduct two research projects in a third international container terminal in the country (Caribbean side).

The remainder of this paper is organized as follows. The design of the "As is" business process model is detailed in section 2. Section 3 defines the basic aspects for the development of the discrete event simulation for the berthing process. The experiment and main results is presented in section 4 while the conclusions are given in section 5.

2. Berthing Process BPMN

2.1 Case Study: Container Terminal at the Pacific entrance of the Panama Canal

Since 1995 with the privatization of public ports in Panama, the Panamanian terminals have experienced an exponential increase in container traffic flows. As a result, the Panamanian ports have ranked first in the Latin American ranking of busiest container terminals from 2011 until these days (ECLAC, 2014). The Balboa Container Terminal is located at the Pacific entrance of the Panama Canal; sharing its seaside operations with the Panama Canal Authority because it is located alongside the inner access channel of the Panama Canal.

Handling an estimate of 3.2 million TEUs annually implies more than 1,500 containership arrivals, spread within a weekly average of 25 calls. Port of Balboa is a 90% transshipment hub terminal and uses Rubber Tire Gantry Cranes (RTGs) -Tractor Trailer Units (TTU) system as horizontal means of transport between the Gate – Storage – Berth subsystems and specialized quay cranes to serve the ships. While the latest RTGs models that have been deployed at the port use hybrid energy systems (electric and fuel), TTUs are heavy duty diesel vehicles (HDDV).

For the development of this model the berth subsystem had to be analyzed from a technical and operative perspective. Technical aspects taken into consideration were infrastructure and superstructure available (quays and quay cranes at berths) as well as characterization of customers (containership structural size and workload). By the other hand, operative aspects are service strategies implemented by the terminal that have an impact, together with the technical considerations, on key performance and environmental indicators measured in this subsystem. Some of these measurements in the process are the frequency of calls and time the ship or "entity" spends in each part of this terminal subsystem.

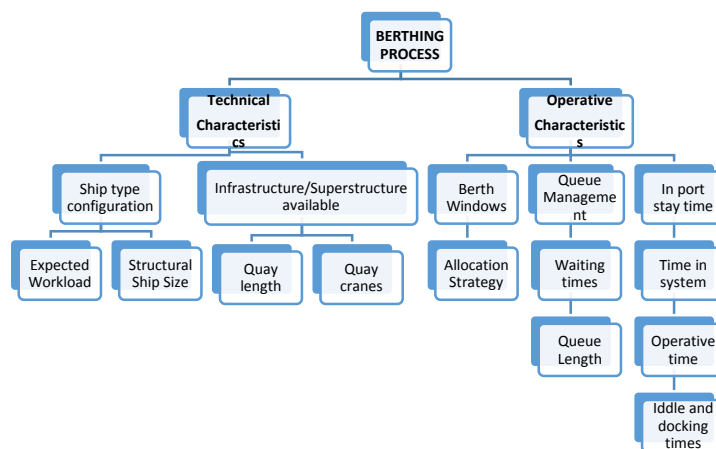


Figure 1. Technical and Operative Characteristics in the berthing process. Adapted from (Camarero, Alberto, 2013).

The Business Process Model for Berthing process at the terminal in study is composed of the following phases:

The containership arrives at anchorage (1) based on berthing schedules or “berthing windows”. In the model, arrivals are modeled in a mixed composition of probability distributions and Schedules. If the vessel arrives in its expected berth window or there is the possibility to begin the berthing process, Port of Balboa Ship Planners and Marine Service Departments request Panama Canal Pilots (PCP) and Tugs assistance for moving the vessel from anchorage to its corresponding berth (2). In case PCP - and Tugs are available for placing the vessel at berth, these resources move the vessel to the assigned berth, otherwise, the vessel queues at anchorage until all resources are available (berth, PCP, tugs). It is important to mention there are two tug companies available to offer this service to Port of Balboa, but only Panama Canal Pilots can maneuver the ship through the inner access channel of the Port due to Panama Canal restrictions (3). The queue presents a mixed behavior of First in First Out sequence plus the assigned priority logic (4) depending on the type of vessel (vessels where prioritized according their structural characteristics). Marine Service Department from Port of Balboa proceeds to moor vessel in the assigned berth (5). Customs inspects load documentation while discharge is being processed by the container terminal (7). Yard and Ship Departments coordinate and monitor load and discharge processes (8). When load sub process is completed, the Ship Planner asks for the Chief Officer’s Outbound Baplie approval which is an electronic data file given from the Port Terminal to the shipping line, and this archive contains the load plan of the bays recently worked in the terminal (9). Once the Outbound Baplie is approved, the vessel is removed from the system by the PCP and Tug Company (10). See figure 2.

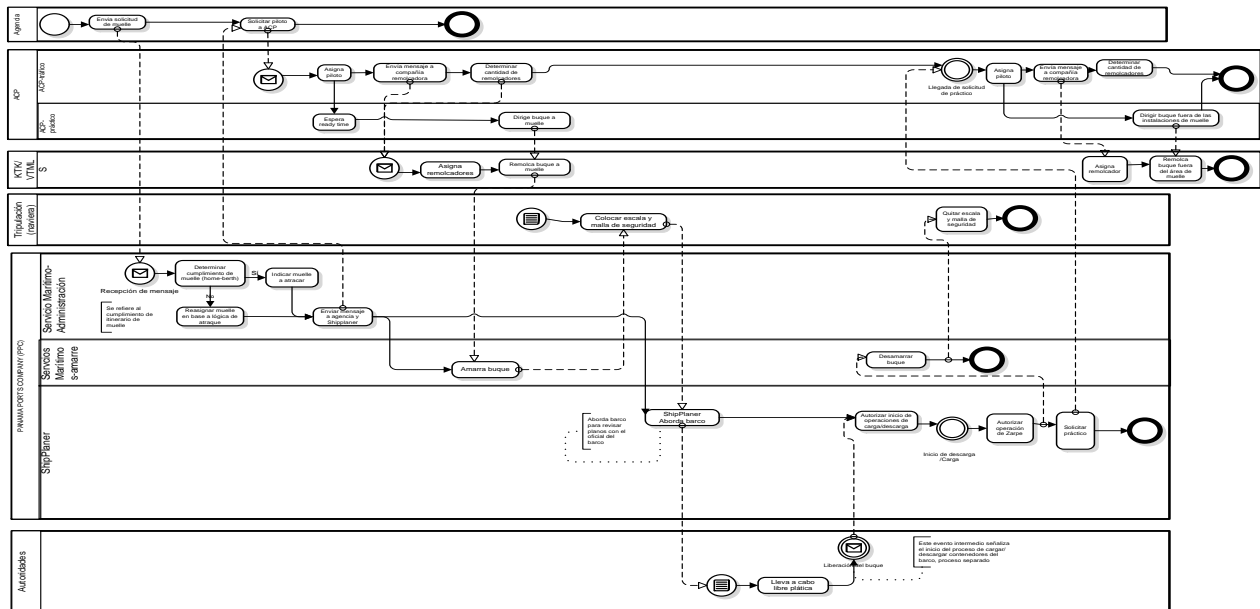


Figure 2. Business Process Model Notation for Berthing Processes at the Container Terminal in study (Caceres, 2014).

3. Discrete Event Simulation (DES) for a Panamanian Container Terminal

This module of the simulation model was built on AnyLogic University 6.5.1XJ Technologies, 1991-2010, educational license. The statistical analysis from three month data related to ships inter-arrival times, processing time per container and other times of interest in the system were used to build the model.

3.1 Ship Generation

The first step in the simulation process was the ship type generation. The table 1 gives an example of the frequency distribution of the arrivals. The table was shortened since the actual table would be too long. Please note that, as (Hartmann, Pohlmann, & Schönknecht, 2011), interarrival times are not the only way to feed the generator in the simulation model. In our case, Weibull distribution was used, since it was the closest fit to the raw data.

2012		
Types	Arrival frequency	Probability
Panamax type 4	87	22%
Panamax type 3b	38	10%
Feeder type 4b	34	9%
Feeder type 3c	32	8%
Feeder type 4c	32	8%
(...)	(...)	(...)

Table 1 Arrival distribution of ships per size

3.2 Queuing Model

The queuing system entity in this model, the “ship”, is defined by a java class. The queuing behavior is governed by an active chart that designates a first in first out sequence for Panamax or smaller vessels (87% of the calls), and a priority sequence for Postpanamax vessels (13% of calls) as shown in the following figure.

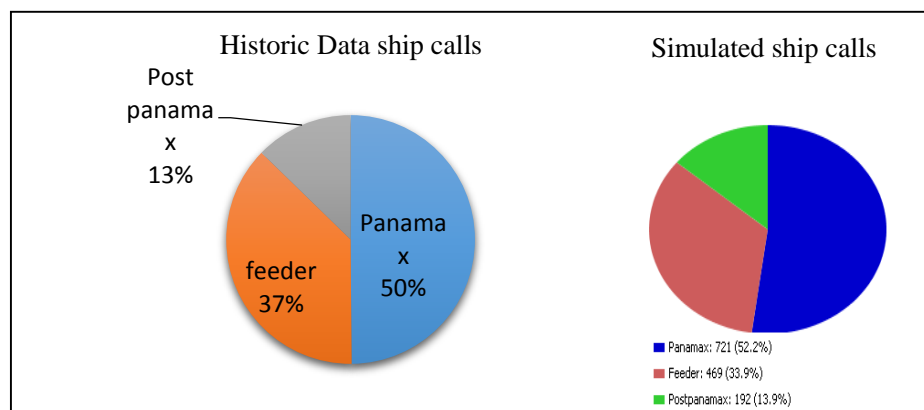


Figure 3. Categorization of ships according to their structural size according historic data vs. Simulated (Caceres, 2014).

Processing times are simulated under triangular distributions, having the possibility to vary these times for testing purposes during a simulation run. The study was verified in its first stages, comparing real data statistical analysis of the different times collected in the sample versus the simulated records of one simulated year (8,760 hours). The following figure shows the graphical interface of the DES model logic in the simulation software.

The sizes of the container fleets that are deployed and later served in a specific port tend to be somewhat consistent within a year, because the containership segment is based on liner services. Length, beam and draft of the received vessels, as well as package size are of main interest when planning strategic, tactical and operational decisions in berthing processes. Port of Balboa is characterized for being composed of many different sizes of vessels served (Dynamar B.V., 2008).

Including this categorization in the java class of the entity, also allow us to simulate the current contribution in CO² emissions per ship type operation in a realistic way, and to generate experiments assuming different ship types calling at the port in study (as the effect of cascading effect on Latin American ports). According to the vessel's structural size there are three main categories of customers (Feeder, Postpanamax and Panamax), but considering the amount of work it was possible to categorize 17 different types.

The model quantitative and qualitative data analysis was performed taking a sample of 400 calls. Random events such as arrival of vessels into the system and service periods, waiting times, docking times, among others are statistically analyzed and introduced into the model. Qualitative data collection methods were observation, on site surveys, interviews and questionnaires.

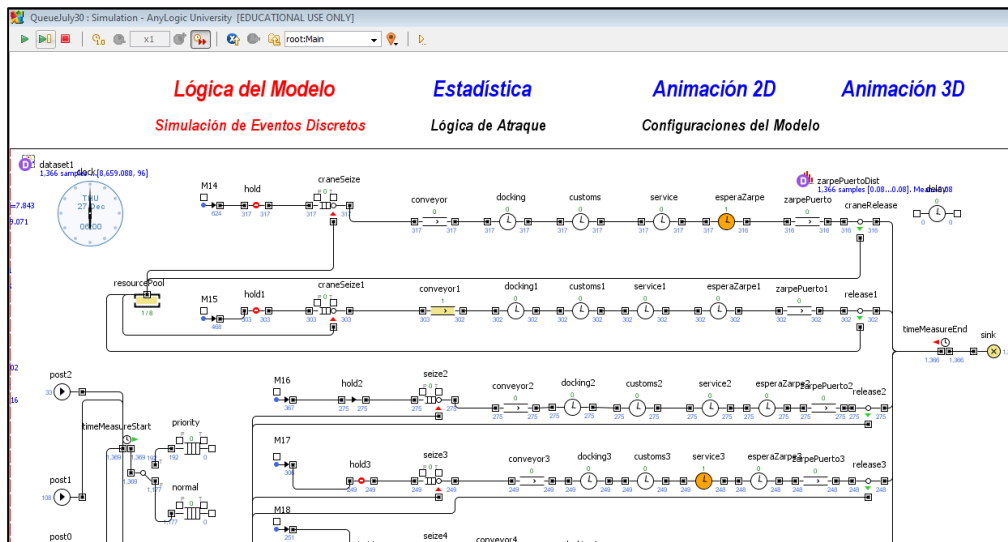


Figure 4. Graphical interface of the DES model logic used in the simulation software (Caceres, 2014).

4. Experiment and Results

4.1 Probability distribution for the simulation ships' generator:

Interarrival times (IAT) are represented in the model by a probability distribution from a data set, resulting in a Weibull distribution. Several runs were conducted to determine the appropriate inter arrival time intervals testing the Weibull equation. The validation of the IATs used in the model is shown the figure 5:

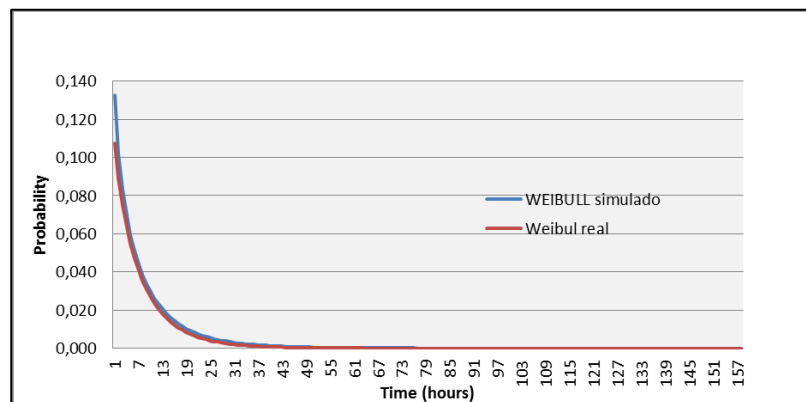


Figure 5: Comparison between the Real IAT data and the simulation IAT outputs using the Weibull distribution fit

Anylogic has an integrated resource from its library called "table function" in this model "shipArrival", integrating the different sources in the model, a "source" generating 87% of the arrivals through the probability function detailed above (Panamax and feeder types) and the rest programmed by an arrival schedule. In the historic data, Postpanamax vessels showed a weekly arrival (ATA), according windows scheduled by the terminal (ETA) with a minimal divergence of two hours.

The "IAT" tested in 20 runs resulted in a 90% confidence interval between 2.5 to 10.21 hours with an error margin (ϵ) of 4 hours.

4.3 Results

- Service Time Structure
 - The model contains a bar chart unifying the times of interest when studying berthing processes, to have an integrated view of the status of the "in port time" the ship presents according to their structural characteristics, divided into Feeder, Panamax or Postpanamax main types. This includes

waiting, transit (anchorage or Miraflores Locks - 30%), customs inspection, operative and departure times.

- The generation of these times gives an idea of the overall performance by vessel type allowing a more clear understanding and giving the opportunity to easily visualize improvement areas in localized parts of the process.

Similarly, materializes what was explained in Section 2, unifying key processes associated while serving the containerships indicating the service times which is of interest for decision makers.

In the following figure, it can be observed that waiting times for Postpanamax vessels is about 10% of their time in port, and from smaller vessels it can represent up to 40% of their total in port time, which means their waiting time is between 4 to 15 hours 75% of the times, comparing both, historical and simulated data.

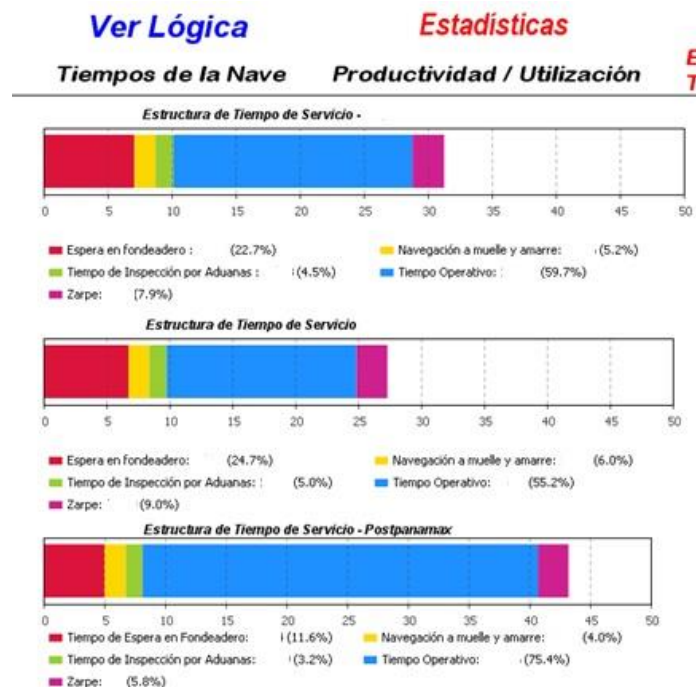


Figure 5. Berthing time structure in hours (Caceres, 2014).

- **Model Validation:** one month simulated processed containers vs. three months average from historic data (third quarter of 2012). Maritime industry trends fluctuate due to exogenous variables affecting the system, contributing to the non-predictability of the demand or production of service times while it uses to happen in most queuing models. Due to confidentiality of the data, the authors could obtain only 400 calls, during the third quarter of 2012, and the provided data was used to contrast through statistical analysis one month of processed containers generated in the simulation.

In a long run validation, the most data available, the best the visualization of the system behavior can be evaluated. Inter arrival times

For example, historical data shows variation among months of 8% in the past three years of 2010, 2011 and 2012, with an average of 152.952 containers handling per month. However, by 2010, although it showed signs of recovery from the fall of 2009, it would not be representative adding the average movements made of 136.568 containers in 2010 to 2011 average of 159.062 or 2012 average of 161.248 containers per month. Even within the year, it can be observed significant falls in the "seasonal" months assumed by periods of Christmas where it would be expected to be observed some pics in demand.

- One month of generated throughput in the simulation multiplied by 12 months and by the terminals Teu factor 1.69 meant a generation of 3.026 million TEUs (1.76 million containers) in the simulation, while it was registered that the terminal handled 3.2 million TEUs (containers 1,934,972) in 2012. Throughput in 2013 were 1, 841.481 or 3.1 million TEUs.

- On the other hand, the same historic data was analyzed in the commercial software Chesscon Capacity Tool, developed by the German company Institute of Shipping Economics and Logistics - ISL GmbH. The analysis consisted in determining the systems' berthing capacity. Even though, AnyLogic proposed in this research. Even Though, data treatment differed in methodology same results were obtained. (3.10 million Teus generated in 2012) and similar waiting times according different ship types (Schütt, Meier and Caceres, 2013).

5. Conclusions

The development of the discrete event simulation for processes associated to berthing processes in the terminal in study took into consideration the analysis of the interarrival times and services that are iterated by probability distributions from statistical analysis of historical data.

At the time of this report it was estimated the analysis by confidence intervals for the "throughput" or container movements expected for the simulated month. The reliability of the time interarrival time for the different ship types was validated before starting the analysis of output indicators.

Simulation models for complex systems are useful for defining and understanding the dynamics of a queuing systems and its relation with various performance indicators. It must be also observed that modeling of subsystems is a conceptual simplification and that in reality the terminal operates as an integrated system, thus the modeling approach to localized systems can negatively affect the rest of the activities (Monfort et. al. 2012) if a holistic view is not undertaken at the same time.

Therefore, Business Process Model methodology was implemented to model the berthing process of a containership in the terminal in study, leading to a high abstraction level or "handoff" model, as a tool to increase the visibility of the berthing processes, actors involved and steps and times taken since ships arrival to its departure with the objective to complete each vessels 'service order (discharge and load containers) according agreed schedules.

This "handoff" model contains valuable activities that the company performs with the aim to offer a competitive service. There have been several initiatives within the company as business flowcharts and reports, but the main difference in the proposed model in this study is the creation of a discrete event simulation based on BPM and queuing systems defining the ship as the entity of interest and mapping the different activities and steps that are necessary to provide the agreed service to the shipping lines.

By understanding queuing systems theory, key elements were identified, from two different perspectives: customer orientation (any entity arriving at the facility and that requires service) and servers (any of the resources assigned to provide the requested service). The customer or the vessel was modeled requesting the services of: pilotage, tugging, mooring, load and discharge of containers and departure, all contained in the "berthing process". To make it possible the identification of actors directly involved in the operative tasks of the six different companies was necessary. Each process components were measured using historical data to obtain:

- Interarrival times of container ships (Weibull distribution).
- Waiting time at anchorage
- Transit times from anchorage/Miraflores locks to berth and vice versa
- Mooring time
- Customs inspection time
- Loading and unloading operations
- Waiting time for PCP and tugs
- Departure

Once simulation runs where performed with these inputs, a comparison was made to ensure simulated data patterns were consistent to the following historical data outputs of the terminal:

- Productivity
- Utilization
- Throughput
- In port stay time by vessel type
- Times in system by vessel type

- Mooring time by vessel type
- Operative time by vessel type
- Waiting time by vessel type

Inferences from the general statistical analysis and empirical data and other results:

- Half of the sample presented waiting periods between 5 and 10 hours.
 - From the business process model it is obtained that there are waiting times generated from activities that occur in anchorage that are beyond the reach of the terminal operator as the FIFO queue behavior for the assignment of Panama Canal Pilots and some of the time the tugs assignment.
 - integrity in agreed estimated times of arrival ETA vs. the actual time of arrival (ATA) varies 65% of the time, within an standard deviation of two hours agreed among the terminal and the customer.
- The inner access channel allows single lane transit to the Port in Study and presents restrictions due to tidal variation and bridges 'of the Americas height for Postpanamax vessels. It is the same access channel used by PSA International container terminal, Panama Canal and minor facilities currently located in this area. There are plans to locate a 3rd international terminal with the same capacity of Port of Balboa (4millio teu aprox.) in between Port of Balboa and Miraflores Locks (Corozal Container Terminal).
- The gross productivity obtained in the simulation was validated through historical data and reports published by the JOC, 2013 (51 movements / hour).
 - Gross productivity obtained of 20 moves / hour, with a deviation of 5 movements per hour was also verified.
 - The average queue length of the period of simulated is of 2 vessels on average.
 - Utilization of berths in both simulation models (Anylogic and Chesscon Capsi Tool) obtained was 60-70% on average.
 - For Postpanamax vessels waiting times represent 10% of their in port stay time but for 87% of the calls waiting times experienced an average of 40% of their in port stay time.

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Biography

Rebeca Caceres M.Sc. is Professor in the logistics field, and Director of Postgraduate Studies in the International Maritime University of Panama. She earned a Bachelor of Science in Maritime and Ports Engineering and Master of Science in International Transportation and Logistics from the Technological University of Panama and International Maritime University of Panama respectively. She has published journal and conference papers. M.Sc. Caceres has completed research projects with Panamanian Terminals and is Coordinating the First Panamanian Observatory of Innovation in Logistics. Her research interests include simulation, optimization, reliability, ports logistics, and port community systems. She is nominated as member of the Directive Board of the Panamanian Association of Supply Chain Executives (APECA) for the 2015-2017 period and is member of the International Transportation and Logistics Research Center from Panama.

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