Studies of the Carbon Footprint for a Port in the Panama Canal

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Abstract

This paper discusses the development of a distributed hybrid simulation modeling environment for the carbon footprint of a port system in Panama using the High-Level Architecture (HLA). Balboa Port is the largest port in Latin America with a growth rate of 14% in the last three years. A calibrated discrete model of the port was developed to represent the security gate operations and heavy duty diesel vehicle (HDDV) truck deliveries. Another discrete-event federate represents the vessels arriving at the different terminals. Finally, a simple continuous simulation model is a federate that contributes to measure the carbon footprint due to the operations in the port. The carbon footprint continuous simulation model can specify an estimate of the greenhouse gas (GHG) emissions that originate from the delivery of cargo load containers. In addition, estimation of the GHG emissions is also performed for the HDDV truck deliveries using the discrete-event federate as the source of the required events. The distributed hybrid simulation environment being built will allow for the execution of the different simulation models that were built by different experts in order to visualize the port operations with higher realism.

Keywords
System dynamics, simulation, shipping, maritime trade, Panama Canal.

1. Introduction
With the privatization of public ports in Panama since 1995, significant increase in the container activity has been observed at the Panamanian ports. By 2011, these ports have become one of the busiest container terminals in the Latin America, with a growth rate of 20% for the Atlantic terminals and 17.2% for Port of Balboa in the Pacific. The mean growth rate for the rest of the main container terminals in Latin America was 12.3% [1]. Port of Balboa is located at the Pacific entrance of the Panama Canal. It shares seaside operations with the Panama Canal due the fact that it is located alongside the inner access channel of the Panama Canal.

Handling an estimate of 3.2 million Twenty Foot Equivalent Units (TEUs) annually implies more than 1,300 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 traditional quay cranes to serve the ships. While latest arrived RGTs at the port use hybrid energy systems (electric and fuel), TTUs are heavy duty diesel vehicles (HDDV).
However, with the growth of the ports, the human activity and greenhouse gas emissions increase. It is estimated that 5.5% of the total human activity generated annual greenhouse gas emission are contributed by the logistics and transport sector [2]. Moreover, 75% of this previous estimate is contributed from the transport activities in the logistics chain. Based on this, logistics companies like DHL, DBahn and Tesco, have established goals to reduce their emissions from 20% to 30% by 2020 [3].

Considering this growth in activities at the Balboa port, a modeling environment for estimating carbon footprint of a port system in Panama Canal is to be implemented using HLA (High Level Architecture) and RTI (Run Time Infrastructure). The basic federates in the configuration are explained as below:

1. Discrete model of the port was developed in AnyLogic representing security gate and heavy duty diesel vehicle (HDDV) truck deliveries.
2. Gate federate is a discrete event model implemented in Anylogic. Real time data related with ships such as number of resources, interarrival times, service times etc. was used in implementation of this model.
3. Carbon footprint federate is a continuous/system dynamics simulation model developed in AnyLogic that measures Greenhouse gas (GHG) emissions which originate from the delivery of cargo load containers and various activities in the port.

The distributed hybrid simulation environment is being developed using HLA/RTI and will allow for the execution of the Port, Gate and carbon footprint simulation models in order to visualize the overall port operations and the carbon footprint measurements.

2. Port Model

For the development of Port model the berth subsystem was analyzed from a technical and operative perspective (see Figure 1). 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). On 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](image)

The Berthing process is composed for the following phases using Business Process Modeling Notation (BPMN) (See Figure 2):

- The containership arrives at anchorage based on berthing windows.
In the model arrivals are model in a mixed composition of probability distributions and Schedules. If the vessel arrives in its expected berth window or exists 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.

In case PCP - and Tugs are available for placing vessel at berth, these resources move the vessel to the assigned berth, otherwise, go to next step. Ship queues at anchorage until all resources in step 2 are available.

The queue presents a mixed behavior of First in First Out sequence plus the assigned priority logic.

Marine Service Department from Port of Balboa proceeds to moor vessel in berth.

Customs inspects load documentation while discharge is being processed by the container terminal.

Yard and Ship Departments coordinate and monitor load and discharge processes.

When load sub process is done, 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 carrier that contains the load planning bays of vessels carrying containers.

Once approved the Outbound Baplie the vessel has to be removed from the system by the PCP and Tug Company.

Figure 2: As-Is berth Process

2.1 Simulation Study
This module of the simulation model was built on the statistical analysis from historical data related to ships inter-arrival times, processing time per container and other times of interest in the system. This 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. The following graph shows the comparison of the real interarrival times for Panamax and smaller vessels, versus the simulated records and its confidence analysis, showing a similar behavior.

The fleet sizes served deployed in a specific port tend to be somewhat consistent within a year, because 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 [5].
Including this categorization in the java class of the entity, allows 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. 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.

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 on site surveys, interviews and questionnaires.

3. Gate Model
The gate and landside access is another subsystem of the terminal. The Gate in turn is made of the following components: Entry/Exit gates, “Precheck” Area, Gatehouse and Lane. Each of these components has its own set of processes. The defined AS-IS process comprises the main processes handled at the container terminal gate/Land access: Export and import of full containers, which are the most critical processes within the terminal as a material handling system from a profit (“full” movement price is noticeably higher that of an empty) and operational (full container movements on average take 35% more time to process than empty ones) perspective. Figures 5 and 6 below show the processes of export and import in BPMN. Thus the main processes were modeled prior to the implementation of a discrete simulation process, which will be explained later. In the gate/landside subsystem, the
main flows identified are outbound flows (import of full containers, pick up of empty containers) and inbound flows (export of full containers, delivery of empty containers). In the following paragraphs the main processes identified are described and the BPMN notation.

3.1 Deliver container (PR1):
- The process begins with the arrival of the truck at the main gate; documents are verified briefly, as well as the trucker ID.
- A verification to ensure the truck itself complies with the minimum safety measures before entering the terminal is done. In the case of export containers, the export documents for the container are checked briefly by Customs representatives and terminal security officers.
- Once these activities are completed the truck can proceed to the “Precheck” area where the container is checked physically and if minimum requirements of safety and hygiene of the container are met, the Equipment Interchange Receipt is issued by a port officer and handed over to the trucker. Only then the trucker can proceed to the Gatehouse. The gatehouse is the main office of the Terminal, slated for drayage operator services.
- The drayage operator arrives at the gatehouse where he has to go to the verification office.
- The drayage operator goes then to the cashier queue to pay for the “right of entrance” for the export container.
- Once the payment is done, the drayage operator proceeds to put the truck in the weighbridge.
- If the weight of the Container complies with the terminal security measures, the drayage operator is allowed to proceed with the rest of the process.
- Assuming export documents are in order and were cleared beforehand by Customs personnel and other government interested parties, the Bill of Lading, as well as the EIR and truck driver documents are handed over to the verification officer of the terminal.
- If all documentation is in order, the verification officer checks the system and issues the container location within the container yard to the drayage operator, in a document known as the CMS. The drayage operator then proceeds to the container yard.
- The truck arrives at the “Lane”.
- The drayage operator proceeds to hand over the CMS to the verification officer at the “Lane” who enters its information on the database.
- Once the information is in the system, the lane Verification officer issues the Terminal Receipt (TR) to the drayage operator, this document is used as voucher of Service by the trucker to his customer(s). Please note that the processes within the container yard were not included since they were outside the scope of this project. Below, a process diagram using the BPMN standard is shown.

3.2 Pick up of full Container (PR2):
- The process begins with the arrival of the truck at the main gate in the terminal main gate. The trucker provides to the port officers, his credentials as well as the documentation for the Container to be picked up. The port officers check the truck in order to ensure it complies with the minimum security measures in order to enter the terminal. If the truck does not comply with these requirements, it is sent away.
- For simplicity purposes we assume the truck has no container (bobtail) hence it does not require to go through the precheck area. Then, the trucker proceeds to the gatehouse.
- If the custom documentation are not in order (were not handled beforehand either by the shipper or the freight forwarder) the trucker proceeds to the customs and governmental office in order to obtain clearance before getting the CMS.
- Once this procedure is complete, the trucker goes to the cashier in order to pay any due (expenses related to the time the Container had to be stored in the terminal, since its arrival and extra fees in case the container exceeded its grace period after its arrival).
Once these expenses have been paid, the trucker goes to a port officer, to whom he hands over the invoice, bill of lading with the customs seals and any other document required for the container in order to be cleared.

If all the documents are in order, the port officer checks the system and provides the trucker with CMS.

The trucker goes to the container yard, in order to pick up the container.

Once the trucker has been serviced at the Container yard; he proceeds to hand over the CMS to the port officer at the “Lane”, this officer does enter the information into the system.

Once the information has been validated, the port officer issues and hands over the Terminal Receipt (TR) to the trucker, which is useful as a service voucher.

If the truck has to clear its Container the truck will go to the Customs facilities within the port where it will be cleared. If the documentation is in order, the import documents are cleared and only then, can the truck abandon the terminal.

Figure 5: Export As-Is process
Due to the complexity of a multi serial server queuing model and the difficulties of an analytic solution for such a problem, a simulation model was chosen as the best option in order to find a solution for this particular kind of queuing problem [6, 7]. A discrete event simulation was chosen as the best paradigm in order to model the gate subsystem (a queuing model at hart). Besides the discrete simulation paradigm has proven its usefulness across a wide variety of problems in transportation, manufacturing and logistics. For this purpose, Anylogic ™, which is an object oriented simulation software based on Java was used for the modeling. Real world data was used to feed the model (number of resources, interarrival times, and service times) and Easyfit ™ was used in order to fit the statistical distributions to the data (See Figure 7).
The different subsystems of the gate system (Precheck, Gatehouse, “Lane”) were divided into different “modules”, referred to in Anylogic™ as active objects. Each of these active objects contains the sub-process flow, with all its elements included (queues, servers/delays, service logic when required).

4. Carbon Footprint model
Carbon Footprint federate is a continuous simulation model developed in AnyLogic that measures Greenhouse gas (GHG) emissions that originate from the delivery of cargo load containers. Carbon dioxide (CO$_2$) and nitrous oxide (N$_2$O) emissions are calculated by this model. The range of the container vessel’s size is from 4,500 TEU to 12,000 TEU.

The Carbon Footprint model for calculating CO$_2$ and N$_2$O emissions is shown in the figure below (Figure 8).

The primary equation used to calculate emission (in kg) of greenhouse gases is given by following equation [9]

\[
Emissions = engine\ power \times load\ factor \times emission\ factor \times aux.\ fuel\ consumption
\]  

(1)

Where, engine power is maximum continuous rating of vessel engine in use. Load factor represents percentage of maximum power used by the vessel for in-port operations mode. Emission factor value is expressed as quantity of a pollutant released in the atmosphere with respect to activity responsible for release of pollutant. By multiplying the appropriate fuel based emission factor by the specific fuel consumption in auxiliary mode, emission factors for CO$_2$ and N$_2$O (kg/ tone fuel) were converted to power based emission factors (kg/ kW-hr). Emissions of nitrous oxide can then be converted to Carbon Dioxide Equivalents by multiplying the emissions of nitrous oxide by the Global Warming Potential values.

5. Current Work
We are still working in this environment. Different groups and experts are working in different simulation models expanding the capabilities beyond the reported status. Our current work focuses on:
5.1 Distributed Simulation Environment
A major reason for using distributed simulation applications is to enable larger and more complex simulations to be executed by utilizing resources from different simulation components. In our case, we are using different experts and different types of software in order to model different processes of this problem (see Figure 9). This particular need leads to use the high level architecture (HLA) and its object model template (OMT).

![Figure 9: Distributed simulation for our first prototype using HLA](image)

HLA supports the development of simulation applications by integrating other simulation components and tools such as visualization tools and real world systems in a common high-level simulation architecture. This architecture promotes interoperability and reusability of legacy simulation models in order to develop a new, complex simulation [10]. Reuse of existing components may reduce the cost and time required to develop a new simulation and allows the utilization of concurrency in the development process of simulation models.

Interoperability between federates is achieved by three major components: HLA rules, which describe federation and federate responsibilities; the Run-time Infrastructure (RTI), which coordinates the local simulation time managed by each federate with the global simulation time in a federation and controls the data transfer; and the Object Model Template (OMT) which defines data structure, the format of the federates (SOM), and the common information in federation (FOM) [10].

The Run Time Infrastructure (RTI) is a software implementation of the HLA Interface Specification, which defines the common interfaces for distributed simulation systems during the execution of an HLA simulation. We are using the MAK RTI. This Commercial of the Shelf (COTS) enables HLA federations to rapidly and efficiently communicate. “It has been chosen for both large and small federations because of its support for a wide variety of network topologies and architectures (including sender-side filtering for efficient WAN operation), ease of configuration, and its range of supported platforms” (http://www.mak.com/products/link-simulation-interoperability/hla-rti-run-time-infrastructure.html).

5.2 High Fidelity Visualization
Visualization of high quality is very important for training and respect of spatial constraints. SIMbox Graphic Engine is the one that we are starting to incorporate to this distributed environment (See Figure 10). This visualization is beyond the capabilities of software simulation packages such as AnyLogic, Simio, and Arena.

The graphics engine in SIMbox Version 5.6 supports a 3-dimensional ocean. For example, the user can select sea-state levels through 12 that correspond to the Beaufort Scale and its associated wave height of a Calm through Hurricane sea state. “The sea-state generates realistic physical affect on maritime entities. A calm sea state will not rock the entity, while a storm sea state (Level 10) will simulate 29 to 41 foot waves that move the entity and occasionally wash over the decks” (http://www.simigon.com/pdf/ReleaseNotes_56_Light.pdf).
The environment visualized with the different vessels has a higher fidelity even if there are realistic underwater views and lightning effects with the approximation of the physical consequences (e.g., a vessel going through shallow waters can partially sink due to the physics and spatial constraints).

Figure 10: Capabilities of high fidelity visualization from different views (e.g., examples of views: vessel bridge (as seen by the captain), vessel (as seen by a viewer at a distance), bay/port (entire environment))

References

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