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Toward a Simulation Model for Capacity Analysis of a New Port Terminal

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Abstract. With the current growth of the maritime industry, which is a key element for many supply chains worldwide, ports seek to increase their capacity and performance in order to tackle challenges and opportunities created by the increased demand in the industry. Port expansion is an efficient way to meet this objective, but requires important resources and careful planning. Before undertaking such a major project, it is important for a port to have a firm grasp and understanding of its current capacity as well as the expansion's requirements and limitations in light of its traffic forecasts. This article presents the data analysis realized as part of an expansion project of a Canadian port case. The data analysis is executed in order to feed the first simulation model of its kind in this sector that will jointly consider the logistics operations taking place in the current port and its new terminal. This article addresses the first steps of the model's conception through data analysis as well as solutions to problems encountered. As the study is underway, the preliminary results of the work are presented.

Keywords: Port logistics, Capacity analysis, Systems simulation, Data analytics, Bottlenecks

1 Introduction

For the past years, the shipping industry has been subjected to an increasing pressure to satisfy the growing demand of consumers worldwide. In the supply chain, ports are a central node that enable national and international trade, creates the connections between different transportation systems and joins the many producers and consumers to the markets [1]. The shipping industry is involved in more than 90% of freight transport [2] and the transport of goods by the maritime industry reached 10.7 billion tonnes in 2017, which corresponds to a growth of 411 million tonnes in the last year, of which half is attributable to dry bulk products [3]. Knowing this, ports are faced with the need to optimize their performance in order to meet the growing needs of maritime transport [4].

In order to capitalize on the growing demand from the maritime industry, ports seek to increase their capacity and performance at the operational level. Indeed, several options such as the optimization of port logistics operations and the flow of goods [5] by the integration of new technologies [6] and business processes, the use of inland intermodal terminals [7] and port expansion [8] are solutions explored by port authorities.

Generally, when ports aim to increase their current capacity, expansion projects are favored whenever possible. Expansion projects certainly require significant investments, but they are often straightforward and quickly translate into an increase in capacity once completed. The Canadian port authority involved in this study has begun an expansion project through the upcoming construction of a new terminal adjacent to the current port.

An expansion project of this scope raises several port logistics issues, particularly with regard to the adequate sizing of the individual capacity of the various port logistics resources involved in the movement of goods from their entry to the exit of the port and this, for both the current port and the new terminal. As a logistics platform specializing in the storage and transshipment of a wide variety of non-containerized goods, the Canadian port involved in this study must also consider in its traffic forecasts the significant uncertainties inherent to its portfolio of goods. In this context, it is advisable to study the impact of adding a new terminal on the expected increase in the overall capacity of the port by completing an analysis of the potential bottlenecks that may arise both in the new terminal and in the current port according to the individual capacities of the logistics resources studied and the port authority's forecasts.

The main objective of this project is to identify potential bottlenecks, especially regarding railway transports, following the development of a new terminal for a Canadian port, as well as to determine when these bottlenecks arise and to analyze their extent and impact within the new terminal and the existing port. This project uses simulation as its main tool in order to reproduce the movements of the flow of goods and the use of logistics resources studied within the new terminal and the current port through the analysis of different forecast scenarios. The simulation model developed will not only allow the diagnosis of potential bottlenecks, but must also validate the outcomes of traffic that may pass through the new terminal as well as the current port.

This paper presents the data analysis of the port's railway, maritime, road data and traffic forecast. The steps taken in order to adapt and overcome certain difficulties regarding the data are also exposed. Finally, the structure of the simulation model that will be designed for this study will also be discussed. The paper is organized as follows. Section 2 presents the model development, including the model's boundaries as well as the strategies used to overcome gaps in the port's historical data. Section 3 presents the data analysis and section 4 covers the conclusion and addresses future work.

2 Model development

The port of this study is a public-owned medium-sized urban port specialized in the storage and multimodal transport of a large variety of non-containerized goods through maritime, road, and railway transportation. The port authority collects data regarding these three transportation modes. Before creating a simulation of the current port and the new terminal to analyse bottlenecks and their impacts, the port's data must first be analysed since this project is data driven. Both the current port's historical data and the port authority's traffic forecasts for the new terminal have their limitations and peculiarities. Working with this data has presented certain challenges and the approach taken for its analysis has been influenced by its constraints.

2.1 System's Boundaries

The system's boundaries refer to the different elements in the system that are taken into account for the project. The main elements of the system are presented in figure 1.

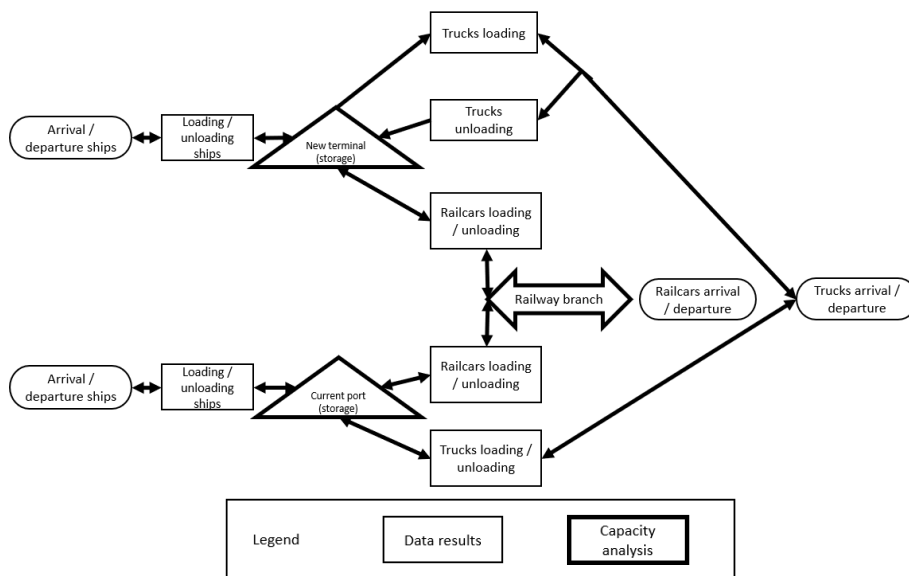


Fig. 1. Model boundaries and processes

Figure 1 includes processes involving maritime, road, rail transport and storage infrastructure. All of these elements are taken into account in the project, but rail transportation is put forward in this study since it is expected by the port authority that the main bottlenecks will be of rail nature and because the railway branch is a shared resource between the current port and the new terminal. As future works in the study, new elements will be addressed and the model will be extended in order to include additional resources and constraints.

Figure 1 can be used to illustrate the flow of goods in four steps in the case of inbound maritime goods that will later leave by road and/or rail. The first step is the goods arrival by vessel at the current port or the new terminal. Then, the goods are unloaded from the vessel and stored in the designated storage infrastructure. When the goods are ready to be sent out, empty trucks and/or railcars enter the port and are loaded. Finally, the loaded trucks and/or railcars exit the port to deliver the goods to the customer. An important element that is taken into account is the railway branch, which limits the maximal number of railcars that can enter and leave the port in the same convoy. Both the current port and the new terminal share this resource since all railcars enter through the railway branch. The port authority asserted that the maximum length of a convoy is 50 railcars and specified certain intermediate thresholds to be observed to analyse the convoy length during the simulation phase of the project.

2.2 Modeling Strategy

In order to overcome challenges brought by the port authority's historical data, a specific modeling strategy was adopted. Because of gaps and uncertainties in the road and rail data, it was determined that it wouldn't be possible to define accurate seasonality and arrival distributions for the road and rail elements. To overcome this problem, the simulation model uses the maritime data in order to generate the trucks and railcars arrivals. Indeed, it is assumed that the trucks and railcars arrivals are heavily dependent of the vessel arrivals, since the vessels will either restock or destock certain goods in the port. With that in mind, it has been assumed that the trucks and/or railcars transporting goods would start arriving a few days after the arrival of a vessel associated with the specific goods for inbound traffic and the opposite situation for outbound traffic.

3 Data Analysis

In this section are presented the results of the analysis of the port authority's maritime, road and railway data. Most of the data analysed comes from the port's historical data between 2015 and 2019, with the addition of data from 2020 for certain types of new goods that will transit by the new terminal. The data analysis presented in this paper was carried out with the overall objective of the project in view, which will be achieved through a detailed simulation of the current port's and new terminal's logistics operations. For this purpose, two main elements were extracted and analysed from the port authority's data, namely the traffic distribution and the transit time of the three different transportation modes. This study takes into account the current port and the new terminal, but with different levels of detail. The current port is treated as a black box in which all the data from different goods are separated in two families according to an outbound or an inbound traffic, while the new terminal is further investigated through the analysis of nine goods' families. Indeed, the current port being already operational with its current traffic, the main focus is on the new terminal and its resource usage, including shared resources with the current port.

3.1 Traffic Distribution

As stated by the modeling strategy explained in section 2.2, vessel, railcar and truck arrivals all depend on the maritime data. For eight of the nine goods' families of the new terminal, the projected distribution of maritime traffic is based on the historical traffic distribution average for the same goods in the current port between 2015 and 2019. For the ninth goods' family, being a new type of product with no history or relatable goods, it was decided to base its projected distribution on the current port's global average distribution. The resulting maritime traffic distributions are presented in figure 2 below.

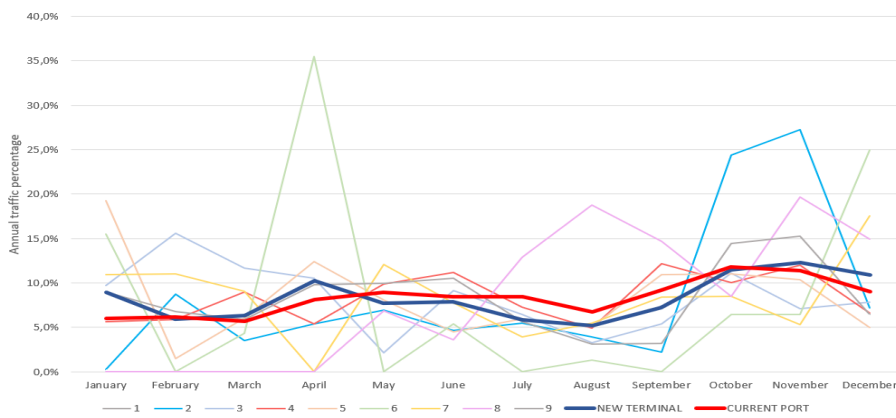


Fig. 2. Current and new terminal maritime traffic distributions

In figure 2, the nine slim and faint lines represent the nine goods' families traffic distributions expected during a full year in the new terminal. The "New Terminal", represented by the large dark blue line, is the average of the nine goods' families distributions, while the "Current Port", represented by a the large red line, is the average of all traffic distributions of the current port between 2015 and 2020, exportations and importations combined. It is noted that both the global terminal and current port distributions are similar, with more traffic during spring and fall (around 10%) rather than summer and winter months (around 5%). These seasonal patterns aren't surprising considering that certain goods are related to certain seasons or activities such as agriculture. Finally, it is worth mentioning, that the similarities between the global terminal and the current port average distributions is a normal occurrence since the new terminal will mainly serve goods already existing within the current port.

Even though rail and road traffic will be dependent of the maritime distributions on a macro level, the day to day traffic distributions of these transportation modes remained unknown, which guided the data analysis towards finding the daily arrival distributions of both rail and road transport over a week. Figures 3 and 4 present the results for these traffic distributions.

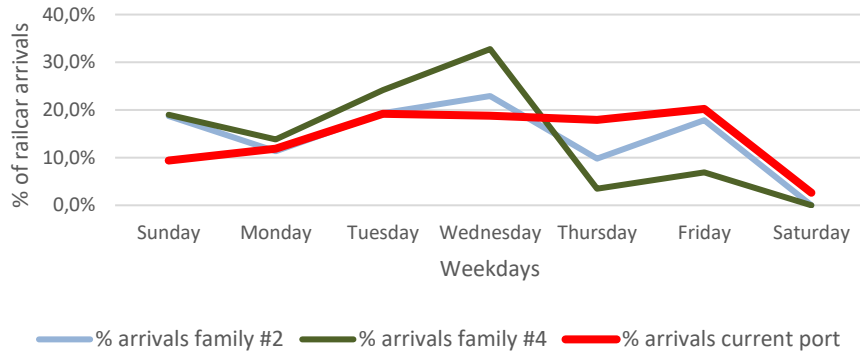


Fig. 3. Weekly distribution of rail transport

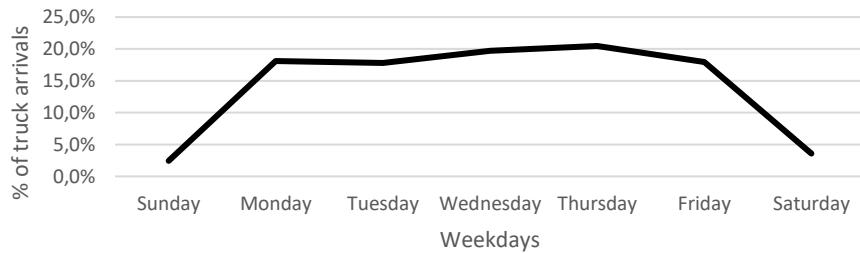


Fig. 4. Weekly distribution of road transport

Figure 3 shows the distributions for the second and fourth goods' families in the new terminal, which are the only families with rail transport in the new terminal, as well as the current weekly rail distribution for the current port, which was obtained through the average of all rail transports of the current port between 2015 and 2019. Figure 4 shows a global weekly distribution for road transport within the current terminal. Indeed, because of the lack of road data, the goods cannot be associated with their matching road transports in the port's historical data, the global distribution presented in figure 4 will be applied to the current port as well as the goods' families in the new terminal.

3.2 Scenarios and maritime input parameters

Using the monthly maritime traffic distributions illustrated in figure 2, the goal is to generate the arrival of vessels for each family within the model following their respective distributions while maintaining the stochastic context. To this effect, the model will use arrival tables with specific dates that follow the maritime traffic distributions. Each individual arrival table corresponds to a ship arrival scenario, and the number of tables used within the model for each family was determined by selecting the minimum number required to reach the targeted distribution.

The data used in these scenarios is the vessel arrivals during the twelve months of a full year. Specifically, in the arrival tables, for every family, the vessels are set to arrive on the fifteenth day of the month at noon. To add a stochastic element, the simulation model then applies to each vessel arrival within the data an offset of more or less fourteen days in the arrival of the vessels. Thus, the vessel will arrive within the programmed month while randomizing the actual day of the arrival. This approach for generating vessel arrivals randomly during the month was chosen after the analysis of the daily distribution of vessel arrivals in a month showed that the distribution was similar over all days.

As implied so far, each goods' families within the model will have multiple arrival scenarios. The scenarios are run simultaneously during the simulation as control variables in experiments. This enables the model to generate vessel arrivals that tend toward the targeted distributions while maintaining the stochastic context.

In order to reproduce faithfully the maritime traffic distributions without overloading the model with an excessive number of scenarios, it was necessary to determine the minimal number of scenarios required to attain this goal. To this end, an analysis was carried out to observe the arrival distribution results for a number of scenarios varying from 10 to 100, as shown by figure 5.

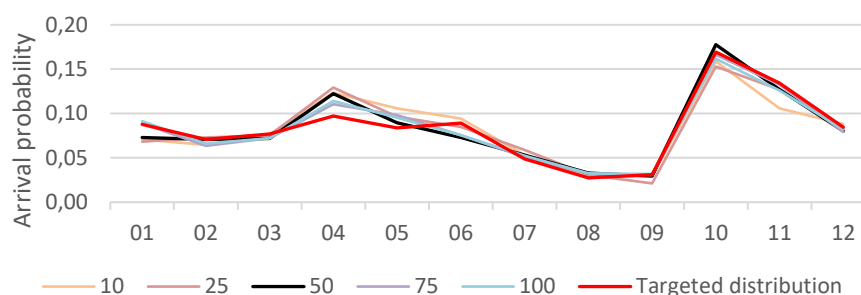


Fig. 5. Vessel distribution for different number of scenarios

After analyzing the data shown in figure 5, the decision was made to use 50 scenarios, illustrated by the black line, since it merges satisfactorily with the targeted distribution, illustrated by the red line. Consequently, the maritime arrival tables for each family uses 50 scenarios. An example of an arrival table is shown in table 1.

Table 1. Boats per month for scenarios (arrival table example)

Scenarios	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Scenario 1	1	-	-	2	-	-	-	-	1	-	1	-
Scenario 2	1	2	-	-	1	-	-	1	-	-	-	-
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Scenario 50	2	1	-	-	-	-	-	1	-	1	-	-

3.3 Transit Time

The transit time for maritime, rail and road transport were determined by comparing the dates and times between the arrival and departure of every transport mode. In the case of maritime transport, it is assumed that the time between arrival and departure is used for loading and unloading operations with minimal wait time. Taking into account the high costs of berthing a vessel, the hypothesis that the waiting time for maritime operations is minimal is used. In the case of rail and road transports, the port's historical data doesn't contain the required information to distinguish process time from idle time, so the time between arrival and departure of railcars and trucks is seen as the general transit time that contains both idle time and processing time. Table 2 presents the transit times for the goods' families as well as the current port for maritime, rail and road transportation. It is worth pointing out that for transit times of the current port, the data was separated in families 10 and 11 to distinguish operation times associated with in-bound and outbound flows of goods.

Table 2. Transit time of maritime, rail and road transport

Goods' families	Direction of flow	Transit time (hours)					
		Maritime		Rail		Road	
		Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1	OUT	92,2	39,4	N/A	N/A	1,67	2,06
2	IN	101,1	48,8	229,4	272,1	1,54	1,99
3	IN	104,9	56,2	N/A	N/A	1,54	1,99
4	OUT	92,2	39,4	49,0	81,7	N/A	N/A
5	IN	95,7	37,4	N/A	N/A	1,54	1,99
6	IN	89,3	38,8	N/A	N/A	1,54	1,99
7	IN	46,0	42,3	N/A	N/A	N/A	N/A
8	OUT	41,8	10,1	N/A	N/A	1,67	2,06
9	OUT	85,2	47,2	N/A	N/A	1,67	2,06
10	IN	74,7	63,5	38,5	78,9	1,54	1,99
11	OUT	83,3	58,9	63,5	97,9	1,67	2,06

For each of the 9 goods' families of the new terminal as well as for families 10 and 11, representing the current port, the average transit time and the standard deviation were calculated using the current port's historical data between 2015 and 2019. The direction of the flow based on maritime transport was also taken into account for the analysis of all maritime, rail and road transportation. In the case of maritime transport, the high standard deviation is explained by many reasons such as the different types of products grouped in a same goods' family that require different loading and unloading times. Also, the variation in the vessel types and weight within each goods' family leads to significant variations in loading and unloading times. In the case of rail transport, the high deviation is explained by the small amount of data used to calculate the rail statistics presented in table 2. Indeed, for the second goods' family, few transports of the goods were made between 2017 and 2019, and in the case of the fourth goods' family, the only rail transports made for this family occurred in 2020 and does not offer a large

data pool. For these reasons, the high standard deviation was to be expected. In the case of road transport as well as rail transport for the current port, represented by families 10 and 11, the high deviation is explained by the fact that a global average of all transports was used, combining the statistics of many highly different goods, resulting in the high deviations seen in table 2.

4 Conclusion

This paper presented the first development steps of a simulation model that will reproduce movements of the flow of goods and the use of logistics resources within a new terminal as well as the current port through the analysis of different forecast scenarios. The main goal of this simulation model is to realize the diagnosis of potential bottlenecks and validate the outcomes of traffic that may pass through the new terminal as well as the current port. The first steps presented in this paper take the form of a data analysis of maritime, road and rail transport using the port's historical data and forecasts for their new terminal. A special emphasis is on the port's rail component since the railway branch presented in figure 1 is an important shared resource between the current port and the future new terminal, and could become a bottleneck for port logistics operations. The data analysis executed in this paper presents transit times for the inward and outward flow of goods of the current port and 9 families of the new terminal for maritime, road, and rail transport. Certain limitations within the data were addressed through the use of maritime distributions to trigger arrivals of road and rail transports. Although, even with limited data, it was possible to determine weekly arrival distributions that specify the arrival of trucks and railcars for each day of the week.

For future works, the implementation of the model using the Simio simulation software will use the data analysis outcomes overviewed in this paper. The model will also be expanded to include additional constraints and resources involving storage and various thresholds within the port and new terminal. To our knowledge, the simultaneous simulation of both the current port as well as its new expansion with the same model and with both separate and shared resources has never been done in this field. This will allow the Canadian port authority to clearly view the impact of the new terminal on its current operations as well as identify potential bottlenecks and capacity limitations for different forecast scenarios.

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