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Evaluating solutions for land border post congestion through simulations

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Executive Summary

Most of the goods traded among the Central American countries are transported by land. Costa Rica has five land border posts. The most important border post is with Nicaragua called “Peñas Blancas”. Approximately 13% of the value of exported goods of Costa Rica are processed through the Peñas Blancas customs office in 2020.

Truck congestion is a daily problem in Peñas Blancas. Based on a time release study carried out in year 2022, it takes, in average, 1037.8 minutes (17.3 hours) to cross the border line from Costa Rica to Nicaragua at this border post. More than 99% of this time is attributed to queues. The first queue can have a length of more the 15 kilometres with an average waiting time of more then 13 hours, just in the first queue.

Between 2023 and 2024, the Border Integration Program of Costa Rica will invest approximately 45 million US dollars to build new infrastructure at the Peñas Blancas land border post. A blueprint of the new infrastructure as well as the new processes have been approved and it is necessary to evaluate if such investment will have the desired impact of reducing the congestion problem.

In this sense, this thesis addresses the capacity problem at the Peñas Blancas land border post by evaluating the existing conditions and future scenarios (one of them being the approved blueprint) for the Peñas Blancas land border post and provide complementary solutions for the congestion problem that might be introduced to the blueprint before the construction starts or is concluded.

The main research question that guides this thesis is the following: By what method can a design be evaluated in resolving a congested truck load export process?

The research approach is based on computer replication and simulation modelling using the FLEXSIM software. The target population of this study are all the cargo trucks (carrying goods or not) that are exiting Costa Rica to enter Nicaragua through the Peñas Blancas land border post. A convenience non-probability sampling is used in this research. Such sampling consists of data obtained in a census. The information is also complemented and crosschecked with data downloaded from the Costa Rican customs declaration system, manual log transcriptions

of the Costa Rican customs authority, customs statistics, participant observation, interviews, and archival records.

Once the database was cleaned, descriptive statistics were calculated per queue and processes to run a model based on the queue theory. The model consisted of a multi-phase line with mostly single servers. For each server in the Costa Rican process, a statistical distribution was determined by inputting the census data into the ExpertFit tool to calculate the most suitable distribution. For each server in the Nicaraguan process, three mean durations were used: one for import, one for transit and another one for empty trucks. Historical statistics were used to determine the distribution of those three processes to assign the average time per process.

Three simulations are programmed:

- Simulation I analyses the Peñas Blancas Land Border post under the existing traffic and operation conditions.
- Simulation II analyses the Peñas Blancas Land Border post under the existing traffic but with the new infrastructure and process based on the blueprint developed by the Border Integration Project of Costa Rica.
- Simulation III is the same as in Simulation II with an additional lane in Nicaragua to process the incoming trucks. Such additional lane contains the three processes: fumigation, police inspection and migration.

Each Simulation is run for 7 days and indicators related to throughput, stay time, states and content are obtained for each queue and server.

Based on 10-day census results of the case study, it was possible to determine that Discrete Event Simulation (DES) using FlexSim and census data was appropriate to understand the “what is going on” with the “as is” process and to evaluate “what if” scenarios without changing the real world.

DES are useful for decision making. In the context of the Border Integration Program (case study of the thesis), the results of the simulation are used to explain the Inter American Development Bank (IADB) the importance of improving either the server time of the Nicaraguan processes or adding an additional lane. The results are also important to justify potential negative macro indicators outputs that are used by the IADB to measure the success of the whole Program. Additionally, the outcomes of the simulations are used to justify the

need to include the Peñas Blancas congestion problem at the Central American Strategy for Trade Facilitation and Competitiveness with Emphasis on Coordinated Border Management of the Council of Ministers for Economic Integration (COMIECO, in Spanish) of the Central American Integration System (SICA, in Spanish).

The main findings of the simulations were:

- The new infrastructure will not improve the current congestion problem in the Interamerican Highway in Costa Rica. The simulation shows that the new infrastructure of the Peñas Blancas land border post increases the length of the queue to migration in Costa Rica. Between Simulation I and II, there was an increase of trucks in Simulation II by 13.4%. Between Simulation II and III there was a reduction by 69.9% of such queue. And, between Simulation I and III, there was a reduction of 65.9%.
- The new infrastructure will not improve the total output of trucks because the Nicaraguan process is the bottleneck. Simulation I and II have the same number of outputs (1377 trucks). With Simulation III, the outputs increased by more than 25.3%, which represents 348 additional trucks.
- The new infrastructure will not improve the efficiency of the servers. Simulation II has a substantial increase of blockage when compared to Simulation I. In Simulation II, three out of six servers are blocked 86% of the time, the other three are blocked between 77% and 74% of the time. All six servers are “idle” approximately 13% of the time and the “processing” time varies from 1% (for migration) to 15% (for customs). The increase in the blocking time is due to the impossibility of trucks to move forward to the Nicaraguan steps. When adding an extra lane in Nicaragua, Simulation III shows that the blockage time has reduced from an 86% blockage in the migration process on Simulation II, it has reduced to 23% and customs process blockage from 77% to 14%.

Acknowledgment

I would like to dedicate this work to my new-born son, Matías. You have been my light ever since I knew you were coming.

I want to express my gratitude to my supervisor Rob Zuidwijk and co-supervisor Morteza Pourakba for their feedback during the development of this thesis.

I would like to acknowledge the support the of Border Integration Project of Costa Rica (Programa de Integración Fronteriza) for allowing me to write my dissertation about the Peñas Blancas land border post and providing information to make this possible.

Finally, I am grateful to my husband Enrique for his love and support; to my parents, who made me who I am today; to my sister who is always there for me; and to the rest of my family for their unconditional love and support.

A handwritten signature in blue ink, appearing to be the Chinese characters '黃晶芝' (Huang Jingzhi).

31 march 2023

Terms and abbreviations

COMEX	Ministry of Foreign Trade of Costa Rica
CR	Costa Rica
CIT	Temporary Import Certificate
DES	Discrete Event Simulation
MCCA	Central American Common Market
NI	Nicaragua
PCD	Drug Enforcement Police
PIF	Border Integration Program
SENASA	National Animal Health Service
SFE	State Phytosanitary Service
SIECA	Central American Economic Integration Secretariat
TICA	Costa Rican customs declaration system
WCO	World Customs Organisation
WTO	World Trade Organisation
COMEX	Ministry of Foreign Trade of Costa Rica
CR	Costa Rica

MCCA	Central American Common Market
NI	Nicaragua
PIF	Border Integration Program
WCO	World Customs Organisation
WTO	World Trade Organisation

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Chapter 1 | Introduction

In this chapter, the research background is introduced by providing an outlook on the current congestion problem that the Peñas Blancas land border post in Costa Rica is facing. After a brief background introduction, it continues with an explanation of the research scope, the way data is collected and discussed. In addition, this chapter includes a brief introduction to the methodology, research design, and the delimitation of the research. The chapter concludes with a presentation of the structure of the thesis and the summary of conclusions and recommendations.

1.1 Research motivation

Between 2023 and 2024, the Border Integration Program of Costa Rica will invest approximately 45 million US dollars to build new infrastructure at the Peñas Blancas land border post. This investment is part of a 100 million US dollar loan from the Interamerican Development Bank (IADB). In addition, the government of Costa Rica has also invested money to equip the new border crossing with technology and optimized processes. Before year 2025 the new Peñas Blancas land border post should be functioning.

A 10-day census was carried out in year 2022 in the Peñas Blancas land border to calculate the border processing time. Based on the collected data, it takes, in average, 1037.8 minutes (17.3 hours) to cross the border line from Costa Rica to Nicaragua at the Peñas Blancas border post. This cycle is calculated from the moment the truck arrives to the queue for the migration process (which is the first processes needed to be accomplished) until it crosses the physical border line. The fastest case recorded took 18.9 minutes while the longest case recorded to cross the border line was 3810.8 minutes (2.7 days). The queue line to Migration (first process) can have a length of more the 15 kilometres in any given day ([A. Rojas, personal communication, February 3, 2023](#)).

A blueprint of the new infrastructure as well as the new processes have been approved and it is necessary to evaluate if such investment will have the desired impact of reducing the congestion problem. In this sense, this thesis addresses the capacity problem at the Peñas Blancas land border post by evaluating the existing conditions and future scenarios (one of them being the approved blueprint) for the Peñas Blancas land border post and provide complementary solutions for the congestion problem that might be introduced to the blueprint before the construction starts or is concluded.

The research approach is based on computer replication and simulation modelling using the FLEXSIM software.

1.2 Research Question

The main research question that guides this thesis is the following: By what method can a design be evaluated in resolving a congested truck load export process?

1.3 Research Delimitations

With the purpose to create boundaries that would allow focusing on the objective of the research, the following delimitations are applicable in this research:

- First, the congestion analysis is only focused on the Peñas Blancas Land Border Post. Therefore, the results of the simulation bounded to such border post. However, the simulation methodology can be extended to other land border posts.
- Second, only cases of trucks (with or without goods) exiting Costa Rica and entering Nicaragua are analysed in this study. The process of entering Costa Rica (import, incoming transit or backhaul) are not considered in this thesis. Consequently, the finding of the research cannot be generalized to such processes. In fact, when modelling only import congestion flow, there is no need to model the export flow, while vice versa is needed.
- Third, only cases that does not involve customs or quarantine physical inspections are considered. Less than 5% of the total number of trucks exiting Costa Rica need to be physically checked by customs and/or quarantine authorities. These are excluded because they undergo a different procedure therefore, they have a different flow of

activities and duration. As a consequence, the model does not consider 5% of trucks that might worsen the export congestion problem.

1.4 Methodology and Research Design

This research follows a quantitative approach. This approach is selected because it investigates the congestion phenomena by gathering quantifiable data to create a queueing model that simulates the current situation (also called “replication”) as well as the “what if” scenarios of trucks processing their exit from Costa Rica to Nicaragua through Peñas Blancas land border post.

The research design “is the logical sequence that connects the empirical data to a study’s initial research questions and, ultimately, to its conclusions” (Yin, 2017). The first component of the research design is the formulation of the research question(s), which is presented in the previous section. Other components of the research design include sampling, data collection, data analysis and presentation of the findings.

The target population of this study are all the cargo trucks (carrying goods or not) that are exiting Costa Rica to enter Nicaragua through the Peñas Blancas land border post. A convenience non-probability sampling is used in this research. Such sampling consists of data obtained in a census collected from the 21st of February 2022 to 27th of February 2022 from all the cargo trucks that were crossing through the Peñas Blancas border post, no exceptions were made.

Data of the census was collected using QR timestamps. Additional information was also used to complement and crosscheck the census data. Such information was obtained using questionnaires, data downloaded from the Costa Rican customs declaration system (called TICA), manual log transcriptions of the Costa Rican customs authority, customs statistics, participant observation, interviews, and archival records.

Once the database was cleaned, descriptive statistics were calculated per queue and processes to run a model based on the queue theory. The model consisted of a multi-phase line with mostly single servers. For each server in the Costa Rican process, a statistical distribution was determined by inputting the census data into the ExpertFit tool to calculate the most suitable distribution. For each server in the Nicaraguan process, three mean durations were used: one for import, one for transit and another one for empty trucks.

Historical statistics were used to determine the distribution of those three processes to assign the average time per process.

The Chapter 3 explains in detail the methodology and research design used in this thesis. The same Chapter also explain the model queuing model used to answer the research question.

1.5 Summary of conclusions and recommendations

Three simulations are programmed:

- Simulation I analyses the Peñas Blancas Land Border post under the existing traffic and operation conditions.
- Simulation II analyses the Peñas Blancas Land Border post under the existing traffic but with the new infrastructure and process based on the blueprint developed by the Border Integration Project of Costa Rica.
- Simulation III is the same as in Simulation II with an additional lane in Nicaragua to process the incoming trucks. Such additional lane contains the three processes: fumigation, police inspection and migration.

Data is recorded from each scenario for 7 days and indicators related to throughput, stay time, states and content are obtained for each queue and server.

Based on 10-day census results of the case study, it was possible to determine that Discrete Event Simulation (DES) using FlexSim and census data was appropriate to understand the “what is going on” with the “as is” process and to evaluate “what if” scenarios without changing the real world. DES were useful for decision making. In the context of the Border Integration Program (case study of the thesis), the results of the simulation are used to explain the IADB the importance of improving either the server time of the Nicaraguan processes or adding an additional lane. The results are also important to justify potential negative macro indicators outputs that are used by the IADB to measure the success of the whole Program. Additionally, the outcomes of the simulations are used to justify the need to include the Peñas Blancas congestion problem at the Central American Strategy for Trade Facilitation and Competitiveness with Emphasis on Coordinated Border Management of the Council of Ministers for Economic Integration (COMIECO, in Spanish) of the Central American Integration System (SICA, in Spanish).

The main findings of the simulations are: (i) The new infrastructure will not improve the current congestion problem in the Interamerican Highway in Costa Rica; (ii) the Nicaraguan processes are the bottleneck causing the congestion at the Costa Rican side, because even if Costa Rica improves the infrastructure or optimizes the processes, if Nicaragua is not able to absorb the incoming trucks, Costa Rica will remain as the parking lot of Nicaragua's import process; (iii) To decongest the queue of trucks in the Costa Rican territory, a new lane could be built in Nicaragua to duplicate the fumigation, police and migration control. With this additional lane, Simulation III has a substantial positive change in the length of the queue of trucks waiting to be processed (from 439 in Simulation II to 132 in Simulation III); the number of trucks finishing the import and export process increases (from 1377 total number of throughputs in Simulation I and II to 1725 in Simulation III), the stay time of trucks in each queue and server are also reduced (from 806.97 minutes in Simulation II to 163.64 minutes in Simulation III).

1.6 Structure of the Thesis

This section provides an outline of the general structure of the dissertation. This should serve as a guideline to help the readers go through all chapters of the thesis.

Chapter 1 – Introduction. (This chapter) presents a brief introduction and description of the research approach used in this study.

Chapter 2 –Case Study Description. This chapter presents a detailed description of the Peñas Blancas land border post processes and current situation. Thorough understanding of the current process is the first and foremost step in modelling the process.

Chapter 3 –Literature Review. This chapter explains the methods and procedures used to search and select the academic sources for the literature review. Then, it presents the review of the research literature with a synthesis of the findings gathered in the review, as well as a critique of the research methods and procedures used in the sources of the literature review.

Chapter 4 – Research Approach. This chapter explains methods and procedures used in this study to allow a reasonable replication. It includes the target population and sampling method followed by all the data collection and instruments. Then, it explains how the simulation model was formulated.

Chapter 5 – Queue Model Results and Analysis. It presents the simulation method selected for case study analysis, provides explanations on its fundamentals, and explains how the replications and scenarios of the Peñas Blancas land border post was modelled based on the collected information. The results of the replication and scenarios are presented and analysed to develop recommendations to improve the truck congestion.

Chapter 6 – Conclusions and Recommendations. This chapter concludes the research with a summary, conclusions and recommendations related to the major findings of the study.

Chapter 2 | Literature Review

This chapter starts with an explanation of the methods and procedures used to search and select the academic sources for the literature review. Then, it presents the review of the research literature with a synthesis of the findings gathered in the review, as well as a critique of the research methods and procedures used in the sources of the literature review. Finally, it presents the main knowledge gaps encountered in the literature review.

2.1 Methods of Searching and Identifying Relevant Literature

In this research, only English articles from peer-reviewed academic journals were used. To select the peer-reviewed academic studies, a list of key words that were needed to perform searches on academic citation databases were generated first. These key words had to be either in the title or in the abstract of the study, otherwise, they would not be considered in the review.

The second step was to arrange the identified key words into search queries and run trial searches (see

TABLE 2.1) before conducting the actual queries at the following major repositories of academic studies: Elsevier (CrossRef), Emerald Insight, JSTOR Archival Journal, Springer (CrossRef), and Proquest Research Library.

Once the trial search was performed and was proven to work, the third step was to carry out the queries and download the articles and store them into the research archives.

The timeframe selected for the search was from 2000 until 2022. Table 2.1 summarizes the queries done in the engines, as well as the amount of hits obtained.

In total, 88 articles were downloaded, the duplicate studies were removed. Then, all articles that had abstracts not related to the topics were discarded. After this process, the remaining 30 articles were revised, and their eligibility was assessed against the two criteria of TABLE 2.2.

TABLE 2.1*Search Queries and Results*

Query	Hits
Queue theory + port congestion	38
Truck congestion + border	21
Truck congestion + border + queue	2
Queue theory + port congestion + process analysis	8
Queue theory + truck congestion + process analysis	8
Stochastic model + truck congestion + queue	11

Source. Own Elaboration.

TABLE 2.2*Criteria for Appraising Eligibility of Candidate Review Articles*

Criterion	Inadequate	Borderline	Good
Relevance to review questions.	Study does not help answer the research question.	Study provides some theoretical or empirical insight that helps answer the review question.	Study provides substantial theoretical or empirical insight that help answer the review question.
Quality of research design.	Description of method is opaque or insufficient; no use of literature or theory; poor data/ unrealistic assumptions.	Description of method is somewhat clear; use of some literature and theory; scarce data / somewhat realistic assumptions.	Method is clearly described; research is rooted strongly in literature and theory; rich data / realistic assumptions.

Source. Männistö (2015).

2.2 Review of the Literature

Most of the articles that addresses queue issues on international trade have their context on seaports, although some focus on truck arrivals at ports were found. Only three academic articles were found that were linked to land border crossings congestion and used queue theory and simulation to address it.

This section is divided into two: (i) literature review about simulation of truck congestion in land border crossings and (ii) literature review about simulation of truck congestion in seaports. Those articles that are focused only on vessel congestions were not analysed.

2.2.1 Simulation of truck congestion in land border crossings

Ashur et al. (2001) examined El Paso-Mexico land border post with the United States. The authors worked to determine an “alternative to prevent congestion at the ports of entry and the associated traffic operations impacts on the road network adjoining the international bridges, while maintaining an adequate inspection of commercial trucks”. They develop a simulation model using ARENA software “to evaluate the existing conditions and future scenarios for the bridge and provide alternative solutions for expected problems”. The inputted data on the simulation model was based on data collected using a stopwatch technique, four times a day for an approximate period of two hours each time. They concluded that the traffic flows the analysed bridge was working efficiently with the current infrastructure and traffic operation, but in future years it might cause spill back to the interstate road.

Suttishe et al. (2019) used activity-based costing (ABC) and simulation techniques to investigate the efficiency of resources consumption and the cost of services provided at the Sadao Customs House (border between Thailand-Malaysia), Songkhla, Thailand. They argue that such cost is needed to later investigate on the truck congestion problems that are present in such border post. They used the ProModel® 2016 software package to represent the real system. Weibull distribution was used in all the processes, except one. The article did not include an explanation on how the researchers selected the Weibull distribution. This simulation was then integrated in an ABC to quantify the cost of each task. As a result, they

argued that combining ABC and simulation can accurately reflect the service cost consumed during the running of the activities because simulation can imitate the working environment.

Haughton & Sapna Isotupa (2012) studied the truck-borne trade flows queues at the Ambassador Bridge international trade corridor at the Detroit–Windsor border crossing (a major Canada–US commercial border crossing). They used computer simulation to predict the potential impact of introducing a system to schedule the flow of freight trucks arriving at the border crossing because it can provide greater predictability of trucks arrivals. The authors also examined if such system could help customs to prioritize their needs with a greater level of resource efficiency. The main contribution of this study is the quantification of the benefit of traffic flow smoothing (for companies and border agencies) in situations when there is a considerable variation in mean arrival rates. They found that without smoothing, significant investment in truck processing capacity at border crossings is needed.

2.2.1 Simulation of truck congestion in seaports

A context-specific work that comes closest to truck congestion in land border post is the truck cargo-handling at marine ports. This section explains the main findings of articles related to truck congestion in seaports.

Chen et al. (2013), Chen & Jiang (2016) and Ma et al., (2019) analysed the truck congestion problem that occurs at maritime terminal gates. The three articles proposed the implementation of a “vessel dependent time windows (VDTWs)” approach to overcome the problem.

In Chen et al. (2013), the authors worked on a case study to analyse the impact of the time windows method, they predicted the truck arrival, estimated the queue length and how the system can optimize the total cost of the system. They used Genetic Algorithm (GA), a multi-society GA, and a hybrid algorithm using GA and Simulated Annealing to run the optimization model. The authors found that the time windows approach can reduce gate congestion as it flattens peak traffic demand. Because of the reduction, the driver waiting time reduces, hence the air pollution caused by the truck emissions. The main limitation of this study is that it cannot be generalized to all container terminals.

In Chen & Jiang (2016), they proposed a framework for implementing the VDTWs approach. They developed optimization models to scale the solution using three alternative strategies.

The alternatives were tested with a fluid flow approach and determined that the fixed ending-point strategy is efficient in various loading volume scenarios and is the simplest to implement. The main limitation of this study is that it does not consider the stochastic nature of gate service system, therefore, there might be some underestimation of the queue length and waiting time.

Ma et al., (2019) focused its study to reduce the long queues at maritime gates as well as the greenhouse gas emissions. The authors worked on a queuing model to describe the current process of trucks and then applied an optimization model based on a terminal appointment system (TAS) with VDTWs. They used a hybrid genetic algorithm based on simulated annealing and found that VDTWs can reduce waiting time of trucks at the gate and carbon dioxide emissions.

Chen et al. (2011) explore how time-varying tolls policy can improve the truck arrival patterns while minimizing the average toll. The paper contributed to the literature by (introducing a “fluid-based approximation functions to model stochastic time-dependent transportation queuing systems”, they found that fluid-based approximation can be applicable to other time-dependent transportation queuing systems.

2.3 Knowledge gap

This work aims to broaden the empirical scope of queueing theory to truck congestion at land border post context. As mentioned before, only three academic articles were found to be directly linked to the desired context. Most of the articles, although some related to truck congestion, were set in a seaport context - see, e.g., Chen et al. (2011), Chen et al. (2013), Chen & Jiang (2016) and Ma et al., (2019).

While several other researchers have also considered modelling a land border post -see, e.g., Ashur et al. (2001), Suttishe et al. (2019), Haughton & Sapna Isotupa (2012) – their work is different from the present research.

This thesis is different from Ashur et al. (2001) because this research models a problem that is already present in the land border post and not expected one as in Ashur et al. (2001). Furthermore, contrary to Ashur et al. (2001) were limited data was available to determine the distribution’s parameters, this simulation work is based on data collected on a census and

enriched and validated with data obtained from customs declaration system and entry and exit logs from the land border post.

This research is also different from [Haughton & Sapna Isotupa \(2012\)](#) because they have a different study scope and data collection for the calculation of distribution varies. These authors explored the scheduling system's performance in a land border crossing, for this, they simulate a Canadian-US border crossing. The study at hand evaluates if the new layout of the infrastructure and processes proposed by the Border Integration Project of Costa Rica can impact the truck waiting time and what other changes might be introduced to improve the current situation. Furthermore, [Haughton & Sapna Isotupa \(2012\)](#) used empirical sources to estimate the parameters of the simulation, none of them are primary sources which can affect the selection of the statistical distribution of the arrival time, processes, etc.

The work of [Suttishe et al. \(2019\)](#) also has a different scope. They are interested to calculate the cost of service and while doing so, they integrated simulation work to run the ABC model. This thesis does not aim to calculate the cost of service but rather estimate the truck congestion on queues and the evaluation of a blueprint design. Methodology-wise, the study at hand shows how the distribution and parameter estimation for the process were calculated in order to allow replication.

Despite the different scoping and design method found in the context-specific work of [Ashur et al. \(2001\)](#), [Suttishe et al. \(2019\)](#) and [Haughton & Sapna Isotupa \(2012\)](#), this thesis also builds from their work. Discrete Event Simulation (DES) model were used in [Ashur et al. \(2001\)](#) and [Suttishe et al. \(2019\)](#) to model scenarios and propose alternative to overcome congestion problems. This thesis builds from their work by using DES to determine bottlenecks, evaluate existing designs and showcase the impact of proposed solutions in a truck congestion international border crossing problem.

Chapter 3 | Research Approach

This chapter describes systematically the methods and procedures used in this study to allow a reasonable replication. It also describes and justifies the methodological approach taken in this research. The chapter starts with the target population and sampling method followed by all the data collection and instruments. Then, it explains how the simulation model was formulated. Finally, to ensure the quality of the research design, this chapter finishes on how the construct validity, internal validity, external validity, and reliability were considered.

3.1 Research Methodology and Design

This research follows a quantitative approach. This approach is selected because it investigates the congestion phenomena by gathering quantifiable data to create a queueing model that simulates the current situation (also known as replication) as well as the “what if” scenarios of trucks processing their exit from Costa Rica to Nicaragua through Peñas Blancas land border post.

The research design “is the logical sequence that connects the empirical data to a study’s initial research questions and, ultimately, to its conclusions” (Yin, 2017). The component of the research design is the formulation of the research question, which is indicated in Chapter 1. This segment explains the procedure to accomplish the tasks of sampling, data collection, simulation model formulation, data analysis and presentation of the findings.

3.1.1 Target Population and Sampling

The target population of this study are all the cargo trucks (carrying goods or not) that are exiting Costa Rica to enter Nicaragua through the Peñas Blancas land border post. Trucks that

undergo customs and/or quarantine physical inspections (around 5% of the total trucks exiting Costa Rica) are not included in this study because they follow a different flow of tasks.

Probability sampling is not possible in this study because the researcher was not able to gather the data from the entire target population. Furthermore, the information needed to develop the model is not easily accessible and it is time and resource consuming.

A convenience non-probability sampling is used in this research. Within the Border Integration Project, a census was performed for the first time at the Peñas Blancas border post. The data was collected from the 21st of February to 2nd of March 2022 from all the cargo trucks that were crossing through the Peñas Blancas border post, no exceptions were made. The collection date does not represent neither a high nor low season, therefore, it does not skew the results. The researcher has access to this data; therefore, convenience non-probability sampling is the most suitable techniques that can be used. The information collected in the census is complemented with additional data obtained through the Costa Rican customs declaration system as well as the records that are hand-written by the customs authorities. Further information about the available data is explained in the data collection section.

In total, 2172 cases of trucks leaving Costa Rica were registered during the census. One case equals one truck. Unfortunately, not all cases contain all the data points per process. This is because the census was collected from 6:00 to 19:00 while the working hours of the land border post was from 6:00 to midnight. TABLE 3.1 shows the composition of the sample per process.

TABLE 3.1
Composition of the sample

Process	Number of trucks registered	%
Migration process	1627	74.9%
Customs process	1441	66.3%
Anti-drug Police inspection	1735	79.9%
Border line gate control	1624	74.8%

Source. *Own Elaboration.*

3.1.2 Data Collection and instruments

Both qualitative and quantitative data is collected. This research uses primary source of data to produce the queuing model. Different instruments are used to collect the information because it increases the construct validity by triangulating the data and the results. Each of the instruments are explained next.

3.1.2.1 QR timestamp recording

A census was performed in Peñas Blancas from the 21st of February to 2nd of March 2022, from 6:00 to 19:00. A total of 2172 (each case = 1 truck) was collected.

The data collection was planned in such a way that each cargo vehicle that entered the border post was treated as a case and was followed up until it left the customs premises. The data collection period was seven days (one week), however, the data collection ended on day 10 to collect the information of the vehicles that entered from day one to seven but did not leave the customs premises by day seven. In other words, on days eight, nine and ten, only the procedures that remained unfinished were recorded.

This census collected the time taken in all the queues as well as the subprocesses that are needed for the truck to exit Costa Rica through the Peñas Blancas border. These subprocesses are migration, customs, drug enforcement authority and customs checkpoint before leaving Costa Rica.

When starting the queue to enter the border post premises, the pollsters adhere a unique QR code to the truck, the customs documents, and the passport. The QR code is same in these three items, but it is unique for each case. This QR code is scanned at each station to mark the beginning of the queue and the beginning and end of each subprocess.

3.1.2.2 Questionnaire

Besides tracking the truck with a QR code, a short questionnaire was also applied to the truck drivers. It was a closed questionnaire to determine the following:

- Customs regime applicable to the cargo (export, transit, or empty truck)
- Country of registration of the truck (Costa Rican or foreigner)
- Goods being carried

- Destination of the cargo
- Time the truck driver started the queue to enter the border post premises. Trucks can arrive to the border post anytime, but the pollster only recorded data from 6:00 to 19:00. Therefore, this question was asked to those trucks without QR code and that arrived outside the pollster's data collection working hours.

3.1.2.3 Download data from TICA

TICA is the Costa Rican customs declaration system. It is possible to perform queries at TICA. These queries are used to complement and validate the information collected from the truck drivers. Specifically, the following information is collected and/or verified:

- Date and time in which the customs procedure are concluded.
- Vehicle license plate classification (domestic or foreign license plate)
- Customs regime (export, transit, or empty truck).
- Applicable customs inspections (physical inspection, documental inspection, or no inspection).
- Applicable quarantine inspection.
- Date and time in which the physical or documental inspection is concluded.
- Type of goods.
- Destination of the goods.
- Value of the goods.

In addition to the previous verification, it is possible to obtain general statistics on:

- Total customs declaration received by customs in the analysed period.
- Total customs declaration accepted by customs in the analysed period.
- Dispatched trucks in the analysed period.

3.1.2.4 Transcription of customs logs

The Peñas Blancas land border posts have entry and exit logs. The customs officers manually record the licence plate number, the date, time, and the customs declaration number of each truck that passes through the "south gate" (when entering the border post) and the "north gate" (when exiting the border post to enter Nicaragua). These logs are manually recorded, therefore they are digitalized and used as an input to create the queueing simulation model.

3.1.2.5 Participant Observation

Empirical data is also gathered using the participant observation technique by DeWalt & DeWalt (2011). While using the participant observation method, one needs to opt for one role among the following five types: non-participatory, passive participation, moderate participation, active participation, and complete participation.

For this thesis, the researcher opts for the “passive participation” which means that the person is present in the environment but without participating in any way on the elements under study. This tool provides the opportunity to collect ‘naturally occurring data’ which can be very valuable to understand the reasons for the kilometric congestion at the Peñas Blancas Border Post.

During the process of participant observation, field notes on the behaviour and activities of the congestion is taken. Field notes are recorded in a semi-structured way using a simple protocol that consist of a table with two columns: one column the descriptive notes and in another column the reflexive notes. In the descriptive notes, the researcher collects information related to the events being observed. On the reflexive notes, the researcher writes down her own thoughts regarding the situation that we were observing, this might include any type of impressions, ideas, perceptions, etc.

3.1.2.6 Interviews

Interviews are also performed with actors that could help understand better the problem. Interviews include: Peñas Blancas border coordinator and Nicaraguan customs officers. The interviews have a semi-structured format that allows the researcher to adapt the questions according to the specific needs that appeared when conducting the interviews. The understanding of the context and the knowledge gained through participant observation facilitates the preparation of the questions. These interviews are executed face-to-face and through telephone, depending on the convenience for the interviewer and the interviewee.

3.1.2.7 Documentation and Archival Records

Secondary source of data is also used, such as previous Time Release Study that are publicly available. Additional secondary sources include past records of operational activities; policy papers and studies carried out by international organizations such as the World Bank and the

Inter-American Development Bank, among others. The secondary source data is particularly useful to model the time needed to process the import in the Nicaraguan side.

This information is considered because once the export processes are concluded in the Costa Rican side, it enters directly to the import process of Nicaragua, therefore, knowing the time it spends in Nicaragua helps to understand the whole queue model.

The recompilation of all these studies helps to corroborate evidence from different sources. For instance, it helps to validate information gathered through interviews, participant observation, etc.

3.2 Simulation Model formulation

A simulation is “the imitation of a system based on knowledge or assumptions about the behaviour of the parts of that system with the purpose of obtaining insight in the behaviour of the whole system” ([FlexSim Simulation Software, 2020](#)). Simulation models are “purposeful abstraction of a real-life system which can be used to answer questions or solve problems. It contains only those elements of reality that are needed to answer the question or solve the problem” ([FlexSim Simulation Software, 2020](#)).

To answer the research questions, several simulations are performed. First, the current situation is replicated in a model to determine bottleneck (also called “replication”). Second, two scenarios are built, one with the design blueprint of the new Peñas Blancas infrastructure to understand the impact of such an investment. Furthermore, another scenario is tested, which consist of making some changes on the Nicaraguan import process to decongest the Costa Rican border.

In this research, Discrete Event Simulation (DES) approach is used because the Peñas Blancas’s export process can be broken down into a (discrete) sequence of events in time. Then, each of these event marks a change in the state of the system. The modelled sequence of events is composed by the physical movement of trucks between queues (which are broken down in arrival and exit) and processes that each have a start and an end.

To build a model, the following minimum steps are carried out:

- Gather a detailed description of the system - from how it looks to how it behaves. Based on this description it is possible do define: (i) number of phases; (ii) number of

servers per phase; (iii) number of waiting lines per phase; (iv) the waiting line discipline (for instance, first-come-first serve); (v) the rules of balking and reneging; (vi) the number of trucks that can be continued in each waiting line; (vii) the probability distribution of the arrival of trucks; and (viii) the service rate per phase and server, including the number of resources and processing times. Chapter 4 and 5 provides such description.

- Create a layout of the models. Layouts are important in this research model because they define certain constraints such as the number of trucks that can be waiting in a queue.
- Define the logic of each step or event. The logic includes information related to the arrival patterns, the time it takes to perform a process or the waiting time in the queue. Chapter 5 of this document provides such details.
- Run the model with the replication first and the model with the first scenario and then the second scenario. The replication model refers to the current situation of Peñas Blancas. The second scenario models the blueprint of the new infrastructure in Costa Rica to measure the potential impact it will have, and the third scenario takes into consideration changes in the processes on the Nicaraguan side.
- View and analyse the results of each simulation one by one before moving to the next one. Chapter 6 of this document provides such analysis.

3.3 Quality of Research Design

This section explains the various methods that are used by the researcher to guarantee quality in the research design and outcomes.

The simulation model is built from census data. Simulation I (which is the replication of the current situation) is first built and the results of the model are tested against the results of the actual outcomes of the census data. This allows to determine if the simulation reflects the real-life situation. Once the replication is validated, the other simulations are tested.

Multiple sources of evidence for the collection of data are used. This enables to triangulate the data and check its accuracy. In addition, key informants are used to review the draft of the simulation report, including the Peñas Blancas land border post coordinator of the Ministry of Foreign Trade. The objective of these reviews is to present the findings to

corroborate the results, its interpretation and avoid (as much as possible) misinterpretation of the collected and analysed data.

According to Creswell & Creswell (n.d.), another form to increase validity in the study is to provide “thick description to convey the findings”. In order to “transport readers to the setting and give the discussion an element of shared experiences”. Therefore, this research provides as much information as possible of the observations made by the researcher.

Another suggestion by Creswell & Creswell (n.d.) to increase validity is to spend prolonged time in the environment under study. The researcher has stayed many days in the Peñas Blancas land border post to understand its processes and find empirical solutions to the congestion problems by discussing the situation with locals. Thanks to this, the researcher develops “in-depth understanding of the phenomenon under study and can convey detail about the site and the people that lends credibility to the narrative account” (Creswell & Creswell, n.d.).

In addition, to strengthen validity the researcher discussed with several key informants the factors they consider that have a direct impact on the congestion problem of truck leaving Costa Rica. These factors were analysed in the thesis in order to obtain stronger findings by rejecting rival explanations (Yin, 2017). During the investigation, the researcher was open to receive rival explanations to the congestion problem in order to test them in the simulations.

Chapter 4 | Case Study Description

4.1 Costa Rica and Peñas Blancas Land Border Post

Trade with the Central American region represents a significant volume of Costa Rica's international trade. According to the Export Promotion Agency of Costa Rica (PROCOMER, in Spanish), the Central American Common Market (MCCA, in Spanish) is the third largest buyer of Costa Rican goods, with a relative share of 18.8% of the total export value in year 2021, just behind the United States which represents almost 47% in 2021 (PROCOMER, 2022).

Most of the goods traded among the MCCA countries are transported by land. Costa Rica has five land border posts. Three with Panama and two with Nicaragua. Peñas Blancas (border with Nicaragua) is the most important land border post. Approximately 13% of the value of exported goods of Costa Rica are processed through the Peñas Blancas customs office in 2020, being Central American countries the main export destinations for these goods transported by land (SIECA, 2022). Other destinations include Mexico, United States of America, and Canada. In terms of transit declarations, 75.75% of such declarations go through said customs office (SIECA, 2022).

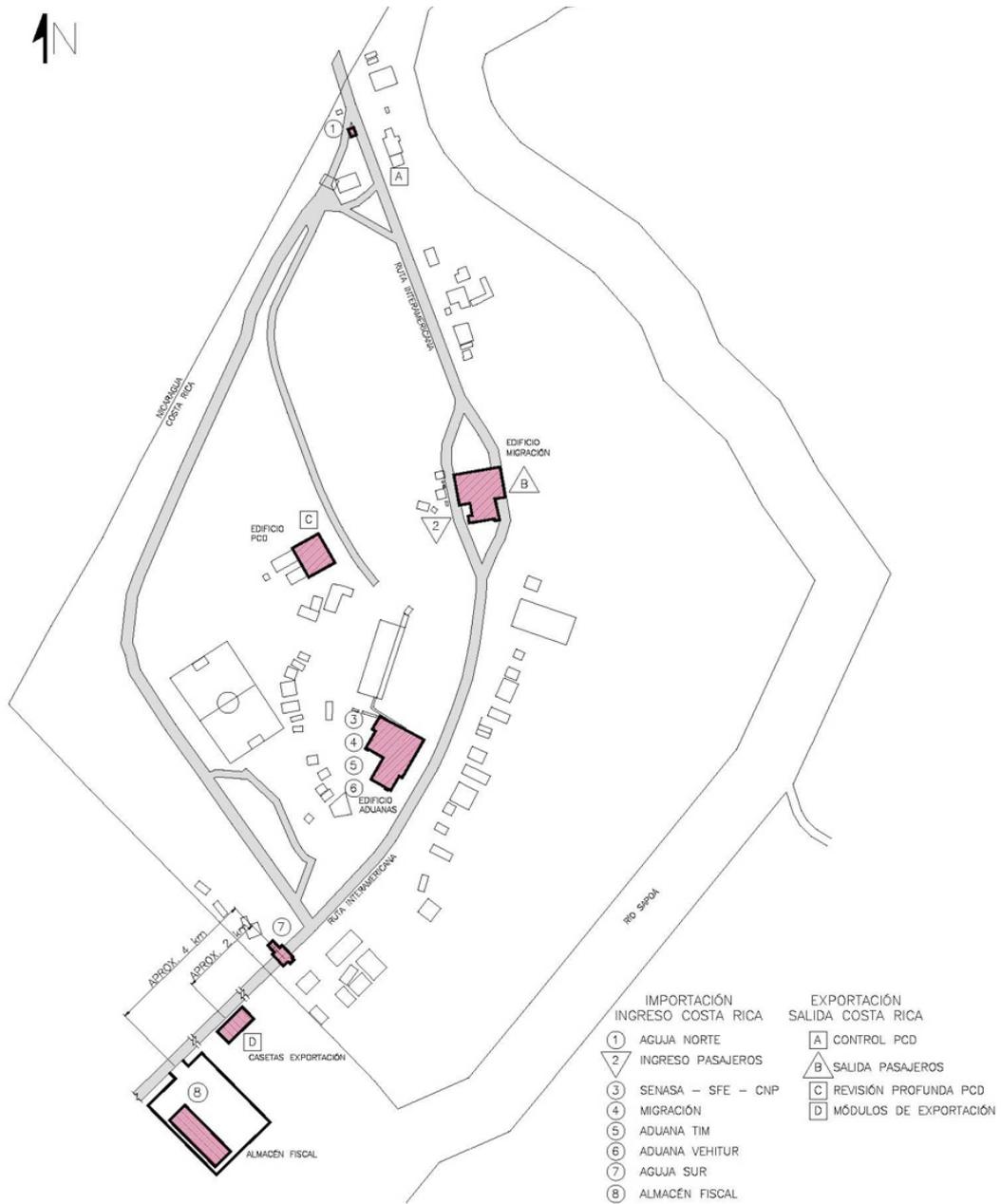
The Peñas Blancas land border post has both cargo (by truck) and passengers' stations. The cargo related processes can be divided into six main broad processes. Three for entering Costa Rica (import, incoming transit and incoming of empty trucks) and three for exiting Costa Rica (export, outgoing transit and outgoing of empty trucks). FIGURE 4.1 shows a blueprint of the Peñas Blancas land border post.

This thesis focuses solely on the exit of trucks from Costa Rica to Nicaragua through Peñas Blancas. The following is an explanation of the three main exit processes that are undertaken at this land border post in Costa Rica:

- **Export regime:** refers to the procedure that involves the movement of goods from Costa Rica to Nicaragua. For this process, the migration procedure and the customs procedure must be carried out in such order. In some cases, the State Phytosanitary Service (SFE, in Spanish) or the National Animal Health Service (SENASA, in Spanish) might also carry out inspections. If the truck has a foreign plate, it has an extra step in comparison to Costa Rican national plates, which is close the Temporary Import Certificate (CIT, in Spanish); this procedure is done by customs. If the goods are not of quarantine interest, all migration and customs procedures are completed at the export booths (point D in FIGURE 4.1). In case of physical inspection by customs, the truck enters the customs warehouse before joining the export booths (point 8 in FIGURE 4.1). Once migration, customs and quarantine procedures are finished, the truck moves along to point A in FIGURE 4.1. In such a place, most of the trucks are screened by the Drug Enforcement Police (PCD, in Spanish). If nothing suspicious is recorded in point A, the truck can continue its journey to the last control at point 1 in FIGURE 4.1 where a customs official checks if the truck driver has all the documentation needed to exit the customs border post. If no inspection is required by any authority (customs, quarantine, or drug enforcement) the truck driver never descends its truck.
- **Transit:** refers to the procedure that involves the movement of goods that is under the transit regime. The flow is the same as in the export procedure, the difference is on the customs paperwork, but the movement through the different stations in the blueprint and described in the export regime does not vary.
- **Exit of empty truck (backhaul):** refers to the procedure that involves the exit of the empty truck only, that is, the truck does not carry any type of commercial goods. For this process, it is required to carry out the migration procedure and the customs procedure (no quarantine procedure is applicable). The flow through the stations is the same as in the export procedure, in other words, the truck arrives to the export booths (point D in FIGURE 4.1) to perform migration and customs, then moves to the drug enforcement inspection (point A in FIGURE 4.1). Lastly, a customs officer checks if they comply with the documentation in point 1 in FIGURE 4.1 before entering to Nicaragua. If no inspection is required by any authority, the truck driver never descends its truck.

FIGURE 4.1.

Peñas Blancas Land Border Post Current Plan, 2022



Source. Ministry of Foreign Trade (n.d.)

Once the Costa Rican exit process has been executed, the next step is to perform the import process to Nicaragua. The Figure below is an aerial photo of the current Peña Blanca land border post on the Nicaraguan side. Number 1 is the international border line between Costa

Rica and Nicaragua. Once the trucks have crossed, they go to the fumigation process (number 2 in the figure). After the fumigation, the truck continues the line until it arrives to the police booth. This authority performs an interview and decides whether the truck needs to be opened or not. After this interview, the truck continues to the Migration procedure to enter Nicaragua (see point 4 in the photo). After migration, the next step is to perform customs process (see point 5 in the below photo), this last step has two booths. The truck driver chooses the one that is opened and free to use.

FIGURE 4.2.

Peña Blanca land border post in Nicaragua

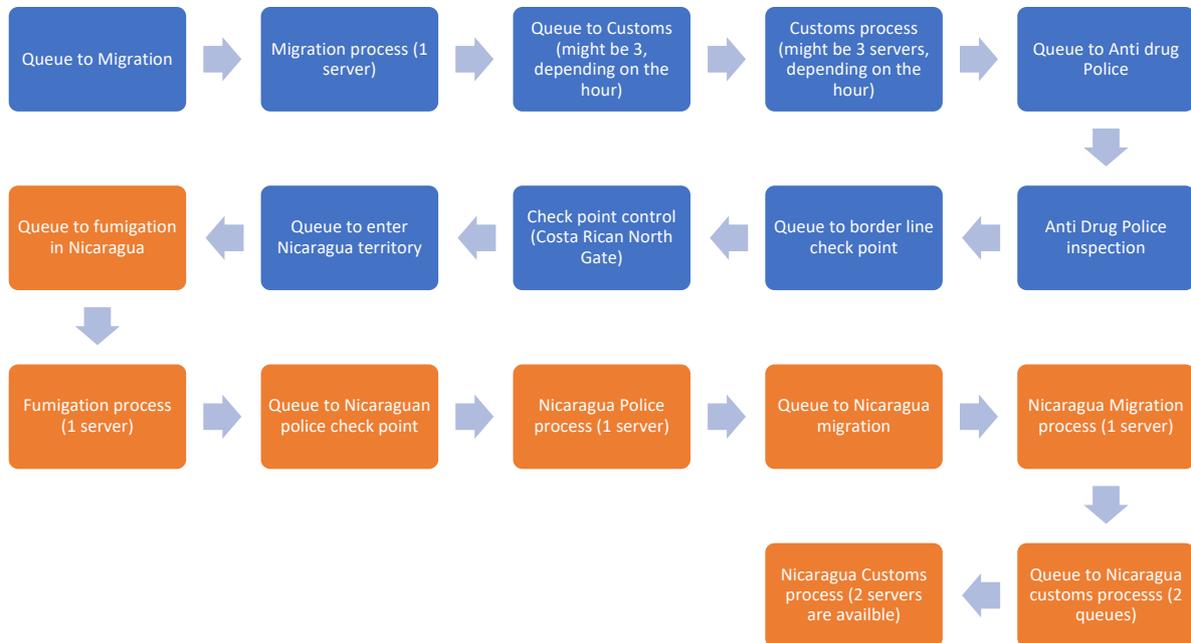


Source. D.Matamoros (2022)

FIGURE 4.3 shows in blue the queues and processes to exit Costa Rica, while the orange are the queues and processes needed to enter Nicaragua. This flow is modelled in the first simulation, which intent to replicate the current reality.

FIGURE 4.3.

Peñas Blancas general export, transit and empty truck queues and processes in Costa Rica and general import, transit and empty truck queues and processes in Nicaragua, 2022



Source. *Own Elaboration.*

According to the most recent Regional Time Release Study carried out by the Central American Economic Integration Secretariat (SIECA, 2022), it takes 3 hours and 49 minutes to export goods from Costa Rica to Nicaragua in Peñas Blancas. In terms of transit, it takes 3 hours and 53 minutes, and the crossing of empty vehicles takes 3 hours with 56 minutes. There isn't any real variation between these three processes (export, transit, and empty truck crossing) because they all must go through the same flow of process as explained previously.

Four hours to cross the border line doesn't sound much, but truck drivers and Central American companies consider that this data does not represent the reality of the congestion experienced by the truck drivers daily. It is common to have a kilometeric waiting line in Peñas Blancas to exit Costa Rica and enter Nicaragua. When analysing the method used to calculate the time in the Regional Time Release Study mentioned above, it was found that this study is not considering the time that the trucks spend waiting to be processed in the first station, which is the Costa Rican Migration process. In other words, the Regional Time Release Study indicators are calculated from the moment the truck arrives to the migration station (this is

the first process that the truck driver must undergo) until it crosses the borderline between Costa Rica and Nicaragua, therefore, the queue to migration is not considered.

The kilometric waiting line is practically present most of the days, however, no study has been performed to understand the reason why the congestion is produced. Some say is the lack of infrastructure, the duration of the inspection of the Police Drug Enforcement, inefficient customs procedures from the Costa Rican export and/or the inefficient import procedure at the Nicaraguan side ([A. Rojas, personal communication, February 3, 2023](#)).

To better document and understand the situation in Peñas Blancas, in 2022 the Costa Rican Government executed a 10-day census to collect new data at Peñas Blancas. This data is unique because it included the waiting time (queues) between all the processes needed to complete the exit from Costa Rica as well as the duration of all the process. Based on this dataset, it takes, in average, 1037.8 minutes (17.3 hours) to cross the border line from Costa Rica to Nicaragua at the Peñas Blancas border post. This cycle is calculated from the moment the truck arrives to the queue for the migration process until it crosses the physical border line. The fastest case recorded took 18.9 minutes while the longest case recorded to cross the border line was 3810.8 minutes (2.7 days). According to the Peñas Blancas coordinator from the Ministry of Foreign Trade of Costa Rica, the queue line to Migration (first process) can have a length of more the 15 kilometres in any given day ([A. Rojas, personal communication, February 3, 2023](#)).

The Costa Rican Government is highly interested to reduce the kilometric queue as well as the cycle time it takes for a truck driver to cross the border from Costa Rica to Nicaragua. Therefore, this thesis project aims to evaluate if this objective is possible to achieve in Peñas Blancas given the designed blueprint of the new infrastructure and processes. To do so, this thesis will first model the current situation of the land border post and then run a simulation on how this queue will behave with the new infrastructure and new processes proposed in the Border Integration Program (PIF, in Spanish). This Program is explained next.

4.2 About the Border Integration Program

Due to the economic importance of the Costa Rican land border posts, the Government of Costa Rica has signed with the Inter-American Development Bank (IADB) a Loan Contract No. 3488/OC-CR, for the financing of the Border Integration Program (PIF, in Spanish). The amount of the loan is 100 million dollars. This contract has been approved by Law No. 9451

and its execution started in year 2017. The main objectives of the Program are: (i) to implement a physical and regulatory system of effective control processes and tools; and (ii) provide the Costa Rican border crossings with the appropriate infrastructure and equipment to respond effectively to cargo and people control processes and tools. To achieve these objectives, the Program comprises two specific components:

- **Component 1. Investments in infrastructure and border equipment:** This component is focused on constructing and remodelling four land border posts in Costa Rica, namely: Peñas Blancas, Pasos Canoas, Sabalito, and Las Tablillas. Infrastructure includes not only the building itself, but also all the hardware equipment needed to control the flow of cargo and people.
- **Component 2. Modernization and integration of border processes:** The objective of this component is to improve institutional coordination for faster and more secure controls. To achieve this, the following actions are taking place: (i) the modernization of the customs information system; (ii) improvement of the Single Window for Foreign Trade; and (iii) the development of a border post management system.

In other words, by the time the Program has finalized, three main results should be achieved: (i) new infrastructure for the four Costa Rican land border posts for the movement of people, goods and vehicles; (ii) implementation of optimized processes to maximise efficiency and effectiveness by reducing time and cost when processing a truck and; (iii) implementation of two new systems: one risk management system for all the border agencies and another system that helps to automate the entry and exit of trucks within the new land border posts.

Performance indicators are established to measure the success of IADB's programs. The indicators are measured before implementing the program (also called "base lining") and a target is set per indicator. This target should be accomplished once the Program has concluded. It is important to achieve the target because it affects the Border Integration Program evaluation and future adjudication of loans and contracts of such Bank.

The following presents the three macro indicators of the Border Integration Program as well as the indicators contained in each one of them:

1. Improvement of the efficiency of border crossings, measured through: (i) Maximum cargo processing capacity of the border post (import and export), measured in terms of trucks per day; (ii) Total cost of the quarantine and non-quarantine control process

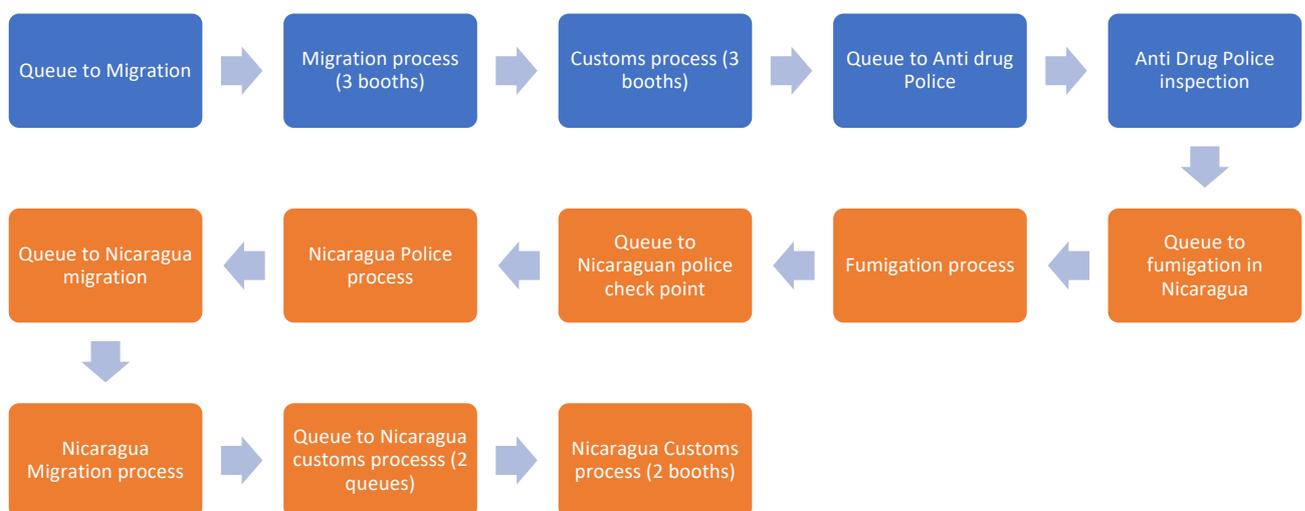
(import and export), measured in terms of US\$ per truck; (iii) Average total border crossing cycle time (import, export, transit, empty trucks), measured in terms of minutes per truck; (iv) Average time spent in queue before starting the control processes, measured in terms of minutes per truck.

2. Improvement in the effectiveness of customs management at border crossings, measured by: (i) Annual percentage of customs operations whose declaration is sent electronically and in advance; (ii) Percentage of non-tariff measures processed through the single windows platform; (iii) Percentage of intrusive or non-intrusive physical inspection, applied to red or yellow channel; (iv) Average clearance time in the red, yellow and green channel; (v) Percentage of declarations that are dispatched without physical inspection, with one physical inspection and with more than one physical inspection.
3. Improvement of the perception of the quality of the service, verified by the Index of satisfaction of the users of the border crossings.

By the time the present thesis is being written, a blueprint has been drafted for the new Peñas Blancas infrastructure, a proposal for the optimized procedures has been presented and the two new systems are being developed. The figure below shows the process flow of the proposed optimized procedures.

FIGURE 4.4.

Peñas Blancas new export, transit and empty truck queues and processes in Costa Rica and general import, transit and empty truck queues and processes in Nicaragua, 2023



Source. Own Elaboration.

This thesis aims to contribute to the Border Integration Program by determining if the blueprint of the new infrastructure and the new processes can help reduce the congestion problem and, in this way, contribute towards the achievement of positive indicators of border cross efficiency macro indicators mentioned before. In particular, the performance of the following three indicators can be simulated in this thesis:

- Maximum cargo processing capacity of the border post (import and export), measured in terms of trucks per day. The target goal of this indicator is 677 trucks a day.
- Average total border crossing cycle time (import, export, transit, empty trucks), measured in terms of minutes per truck. The target goal of this indicator is 22.6 minutes per truck.
- Average time spent in queue before starting the control processes, measured in terms of minutes per truck. The target goal of this indicator is 1.2 minutes per truck.

4.3 Structure of the model

This section describes the main logic of the model, i.e., flow with arrival processes, the queues and processing stages.

4.3.1 Simulation I

This simulation represents the current situation of the Peñas Blancas land border post. All servers are set to work from 6:00 AM until midnight from Monday to Sunday, except for two Costa Rican customs booth/servers. Chapter 5 explain the capacity of each queue, the statistical distribution of the processes, and the inter-arrival time.

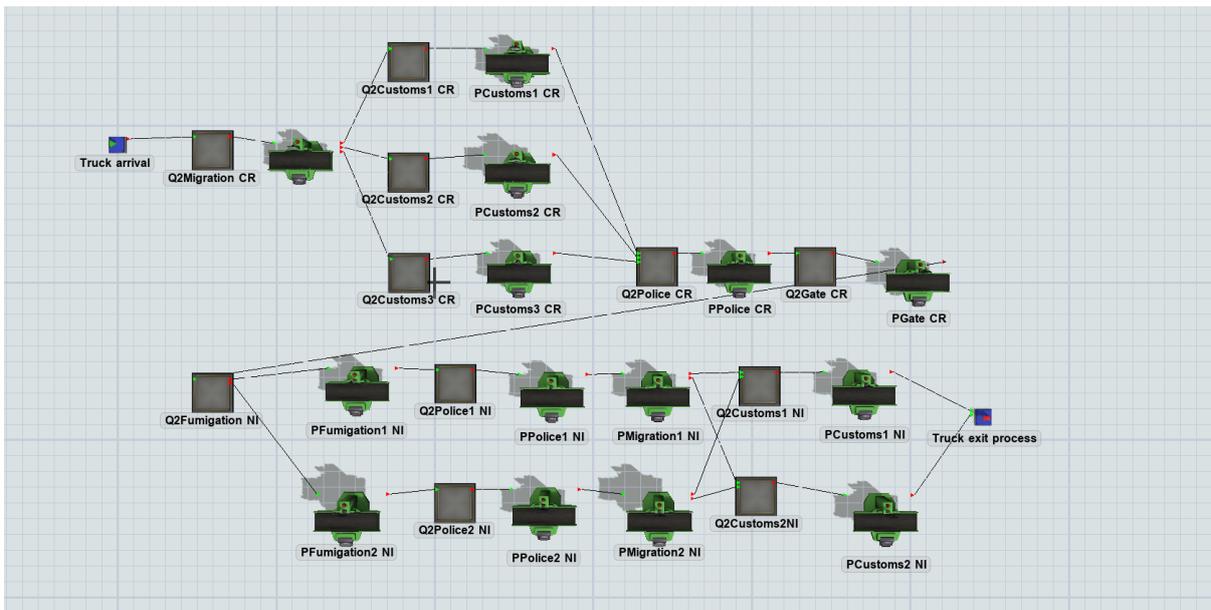
FIGURE 4.1 shows the servers and queues distribution of Simulation I. The model starts with the truck arrival, this is calculated using inter-arrival time based on stochastic information. If there is no one in the queue, the truck goes directly to the migration process (PMigration CR), which has only one server available. The usual is that truck must wait in a queue (Q2Migration CR) to be processed by the migration authority. Once this step is concluded, the truck moves forward to the customs process (Q2Customs 1-2 and 3 CR). This is the only process that has more than one server, however, not all servers have an equal operating hour, one opens from 6:00 AM until midnight (PCustoms 1 CR), another one from 8:00 AM until 20:00 PM (PCustoms 2 CR), and the last one from 10:00 AM to 16:00 PM (PCustoms 3 CR). Once migration and customs processes are over, the truck moves forward into a single queue formed in a single

one lane road heading to Nicaragua (Q2Police CR). All the trucks are inspected by the drug enforcement police (PPolice CR). If the police does not find any anomaly, the truck can move forward to the last queue (Q2Gate CR) to the final Costa Rican checkpoint (PGate CR).

On the Nicaraguan side all processes have a single server except for the customs process. FIGURE 4.1 shows two servers per process but the second server are blocked in the simulation. First, all trucks arrive to the first single queue (Q2Fumigation NI), trucks are fumigated (PFumigation1 NI) and then they move forward to a queue (Q2Police1) that takes them to the Police booth (PProlice1 NI) and migration booth (PMigration 1 NI). After migration, the trucks continue to the final process, which is the Nicaraguan Customs Processes (PCustoms 1 and 2 NI). This last process has two servers. Once the truck has completed this cycle, they may leave the Nicaraguan border post.

FIGURE 4.5.

Simulation I servers and queues distribution



Source. Own Elaboration based on the FLEXSIM Software.

4.3.2 Simulation II

Simulation II represents the Peñas Blancas land border post with the new Costa Rican infrastructure blueprint.

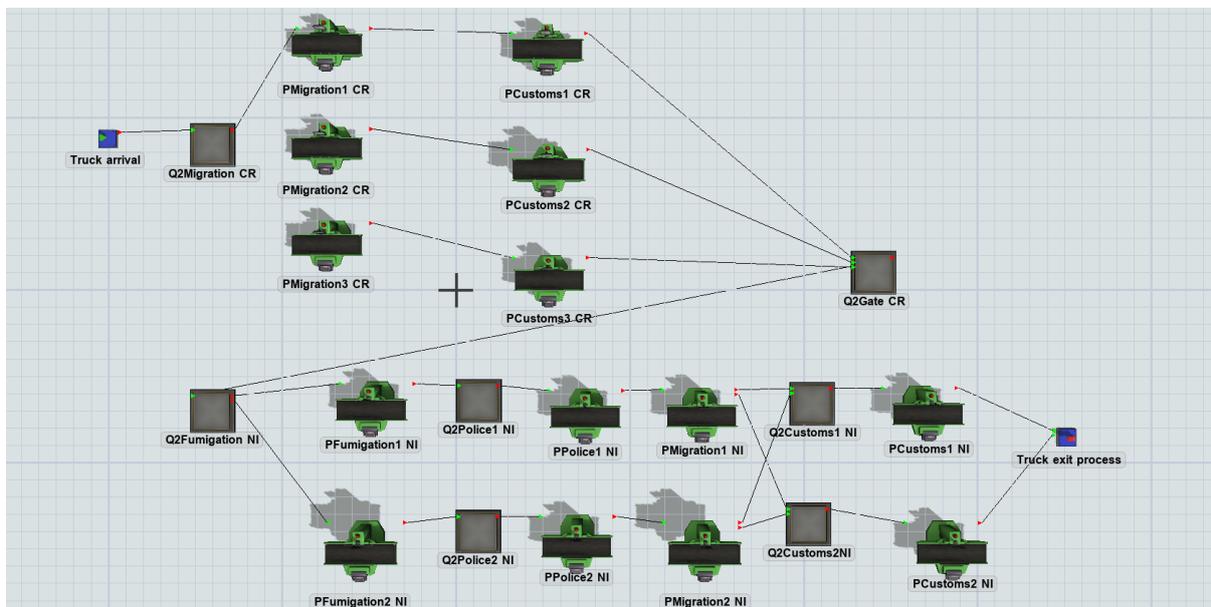
The inter-arrival time of trucks per day did not vary between the three simulations. Furthermore, the processing time of each server remained the same for both Costa Rica and Nicaragua. Some servers and queues in the Costa Rican side were removed as per the new blueprint. The number of trucks that can be lodged in each Costa Rican queue was updated (see chapter 5 for the exact data details inputted in this simulation).

FIGURE 4.6 shows the servers and queues distribution of Simulation II. The model starts with the truck arrival, this is calculated using inter-arrival time. If there is no one in the queue (Q2Migration CR), the truck goes directly to the migration process (PMigration CR 1, 2 or 3). Right after migration and without entering another queue, the truck driver performs the customs process (PCustoms CR 1, 2 or 3). Once migration and customs processes are over, the truck can move forward to the last queue (Q2Gate CR) to the final Costa Rican checkpoint. This checkpoint is automatic, which requires no server.

On the Nicaraguan side all processes remain the same as explained in the previous section.

FIGURE 4.6.

Simulation II servers and queues distribution



Source. Own Elaboration based on the FLEXSIM Software.

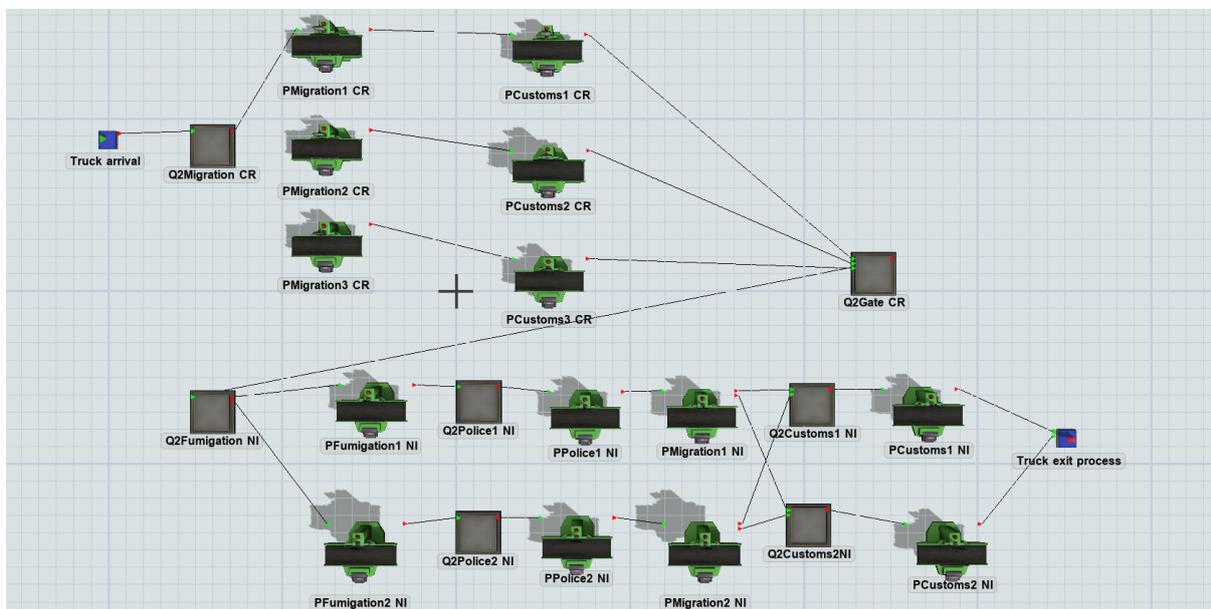
4.3.3 Simulation III

This Simulation III represents the Peñas Blancas land border post with the new Costa Rican infrastructure blueprint plus a new Nicaraguan lane to perform the fumigation, police, and migration controls to enter such country.

FIGURE 4.7 shows the servers and queues distribution of Simulation III. The flow on the Costa Rica side is exactly the same as explained in Simulation II. The process in the Nicaraguan side is what varies: all processes have double servers. First, all trucks arrive to the first single queue (Q2Fumigation NI), trucks are fumigated in either of the lanes (PFumigation1 and 2 NI) and then they move forward to a queue (Q2Police 1 and 2 NI) that takes them to the Police booth (PPolice 1 and 2 NI) and migration booth (PMigration 1 and 2 NI). After migration, the trucks continue to the final process, which is the Nicaraguan Customs Processes (PCustoms 1 and 2 NI). Once the truck has completed this cycle, they may leave the Nicaraguan border post.

FIGURE 4.7.

Simulation III servers and queues distribution



Source. Own Elaboration based on the FLEXSIM Software.

Chapter 5 | Queue Model Setup

This chapter presents the queue model simulation. It consists of a multi-phase line with mostly single servers. Elements that are determined and/or calculated to formulate the model include: number of phases; number of servers per phase; number of waiting lines per phase; the waiting line discipline; the rules of balking and reneging; the number of trucks that can be contained in each waiting line; interarrival time of trucks; the probability distribution of the processes; and the service rate per phase and server. All this information is presented in this chapter.

5.1 Modelling tool

FlexSim's 3D models is used to simulate both the current situation (also known as replication) and the two different scenarios. This tool helps to understand the "what is going on" with the "as is" process and test "what if" scenarios without changing the real world. With these simulations, this research aims evaluate if the Peñas Blancas's blueprint will have the expected outcome and if adding an additional server in the Nicaraguan side would reduce the congestion problem.

The "as is" process is modelled following the flowchart of Figure 4.1. The blueprint scenario is modelled following the flowchart of Figure 4.3. The last scenario adds additional booths or servers in Nicaragua side. The following aspects are considered in the simulation:

- The measurements used in the model are minutes and meters.
- The clock display time is the model's date and clock time.
- The queue capacity is based on a WB-20 truck (which is the most common type of truck).
- No set up time is programmed per process (i.e., setup time equals zero).

- All outputs for queues and processes is “first available”.
- Maximum content per server is one.

Each box in the Flexsim animation represents one truck (see Appendices A for more detail about the graphics and its meaning in Flexsim). The operating time of the land border post is 6:00 to 00:00, therefore, the simulation is programmed to stop processing trucks outside such timeframe. However, trucks may arrive between 00:00 and 6.00, therefore, these trucks will accumulate in the first queue (which is the queue to migration process in Costa Rica).

5.2 Statistical Distribution of the Replication and Simulation

Statistical distributions capture real-life variance. For this simulation model, each of the Costa Rican process of the model has its own statistical distribution to obtain the random duration for the activity.

To define the distribution of the Costa Rican processes, the data collected from census as well as the information complemented from various sources is used. To determine the name of the distribution as well as the parameters that are needed to input in the simulation model, a software called “ExpertFit Tool” is utilized. When importing real data into the ExpertFit Tool, the system analyses the information to determine the most accurate statistical distributions that matches the corresponding data.

To define the distribution of the Nicaraguan Process, mean durations were used. Late 2021, the Central American Economic Integration Secretariat (SIECA, in Spanish) performed a Central American Time Release Study based on the World Customs Organization methodology. This study measured the cross-border land operations in six countries. Such study presents the most recent mean time for each one of the four Nicaraguan processes to allow the entry of a truck to Nicaragua. Each mean time is presented for three processes: import, transit, and empty trucks ([SIECA, 2022](#)). To determine the percentage of trucks that undergo each one of the entry processes, official statistics from the Nicaraguan Customs Administration was used. Based on the statistics, 46.9% of the trucks that enter Nicaragua through Peñas Blancas land border post is transit, 33.8% are importations and 19.2% are empty trucks ([Georgia Tech, 2015](#)). Table 5.6 shows the mean time of each Nicaraguan process in terms of import, transit and empty trucks.

5.3 Interarrival times

The simulation uses interarrival time to model the trucks they are incoming to the Peñas Blancas land border ports. Arrival rate is different from interarrival rate. The first one is the number of trucks per unit time. The interarrival is the time between each truck arrival into the Peñas Blancas land border post and the next one. For example, the arrival rate would be seven trucks per hours, while the interarrival time would be one truck every 8.5 minutes.

Interarrival time is very important, because is the start point in any simulation. In this thesis, the interarrival time is calculated using stochastic data. TABLE 5.1 and FIGURE 5.1 show the number of trucks, per hour and per day, that joined the queue.

It is important to highlight that these data were calculated with the database collected during the census. Because the data collection was carried out from 6 a.m. to 7 p.m., there were trucks that joined the queue at a different time than the information was collected. Therefore, to the extent possible, pollsters asked trucks drivers for the approximate time they reached the queue. Not in all cases an answer was provided.

Based on the number of trucks, the interarrival time was calculated (See Table 5.2). This is the data inputted into the simulation.

TABLE 5.1.
Number of trucks arriving to Peñas Blancas by day and hour

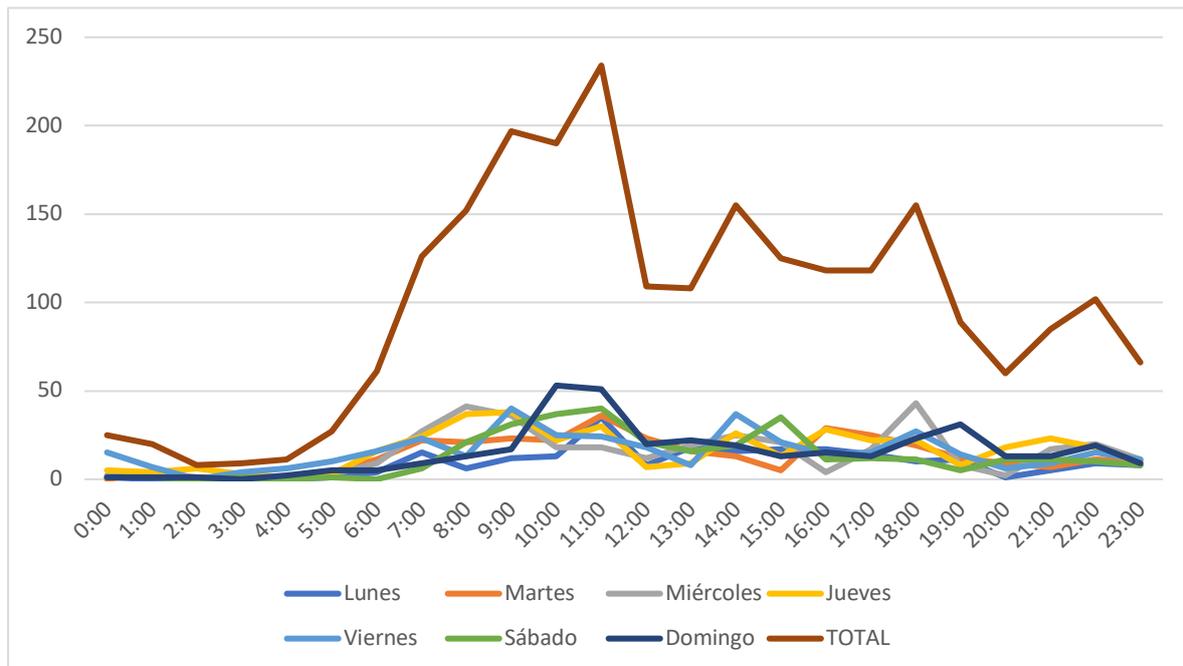
	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL
00:00	1	0	2	5	15	1	1	25
01:00	0	4	3	4	7	1	1	20
02:00	0	1	0	6	0	0	1	8
03:00	0	1	0	3	4	1	0	9
04:00	0	1	1	1	6	0	2	11
05:00	1	4	3	3	10	1	5	27
06:00	4	11	9	16	16	0	5	61
07:00	15	22	27	24	23	6	9	126
08:00	6	21	41	37	13	21	13	152
09:00	12	23	36	38	40	31	17	197
10:00	13	22	18	22	25	37	53	190
11:00	35	36	18	30	24	40	51	234

	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL
12:00	8	23	12	7	18	21	20	109
13:00	18	16	19	9	8	16	22	108
14:00	16	13	25	26	37	19	19	155
15:00	17	5	21	13	21	35	13	125
16:00	17	29	4	28	14	11	15	118
17:00	14	25	17	22	15	12	13	118
18:00	10	19	43	22	27	11	23	155
19:00	11	12	8	8	14	5	31	89
20:00	1	9	2	18	6	11	13	60
21:00	5	7	17	23	9	11	13	85
22:00	9	11	20	18	15	10	19	102
23:00	8	10	11	9	11	8	9	66
TOTAL	221	325	357	392	378	309	368	2350

Source. Own Elaboration based on the census data.

FIGURE 5.1.

Number of trucks arriving to Peñas Blancas by day and hour



Source. Own Elaboration based on the census data.

Table 5.2. *Interarrival time Peñas Blancas by day and hour, in minutes*

	MON	TUE	WED	THU	FRI	SAT	SUN
00:00	60.00	0.00	30.00	12.00	4.00	60.00	60.00
01:00	0.00	15.00	20.00	15.00	8.57	60.00	60.00
02:00	0.00	60.00	0.00	10.00	0.00	0.00	60.00
03:00	0.00	60.00	0.00	20.00	15.00	60.00	0.00
04:00	0.00	60.00	60.00	60.00	10.00	0.00	30.00
05:00	60.00	15.00	20.00	20.00	6.00	60.00	12.00
06:00	15.00	5.45	6.67	3.75	3.75	0.00	12.00
07:00	4.00	2.73	2.22	2.50	2.61	10.00	6.67
08:00	10.00	2.86	1.46	1.60	4.62	2.86	4.62
09:00	5.00	2.61	1.67	1.58	1.50	1.94	3.53
10:00	4.62	2.73	3.33	2.73	2.40	1.63	1.13
11:00	1.71	1.67	3.33	2.00	2.50	1.50	1.18
12:00	7.50	2.61	5.00	8.57	3.33	2.86	3.00
13:00	3.33	3.75	3.16	6.67	7.50	3.75	2.73
14:00	3.75	4.62	2.40	2.31	1.62	3.16	3.16
15:00	3.53	12.00	2.86	4.62	2.86	1.71	4.62
16:00	3.53	2.07	15.00	2.14	4.29	5.45	4.00
17:00	4.29	2.40	3.53	2.73	4.00	5.00	4.62
18:00	6.00	3.16	1.40	2.73	2.22	5.45	2.61
19:00	5.45	5.00	7.50	7.50	4.29	12.00	1.94
20:00	60.00	6.67	30.00	3.33	10.00	5.45	4.62
21:00	12.00	8.57	3.53	2.61	6.67	5.45	4.62
22:00	6.67	5.45	3.00	3.33	4.00	6.00	3.16
23:00	7.50	6.00	5.45	6.67	5.45	7.50	6.67

Source. Own Elaboration based on the census data.

5.4 Queue input data

The queue capacity refers to the number of trucks that the queue can absorb.

In the case of “queue to migration in Costa Rica”, a 10 000 capacity was set even though the queue can be longer but it is not probable under normal circumstances.

TABLE 5.3 shows a summary of the queue data inputted in the replication model (current status).

TABLE 5.4 shows the queue data inputted in the simulation of the new Peñas Blancas infrastructure based on the blueprint. Lastly, the TABLE 5.5 presents the queue data inputted in the simulation of the new Peñas Blancas infrastructure based on the blueprint with an additional import processing lane in Nicaragua.

The physical space of the infrastructure is given; therefore, the queue capacity is calculated based on a standard truck size (a WB-20) which are the most commonly used truck in the region (A. Rojas, personal communication, February 3, 2023).

Queue characteristics refers to the way the truck can be served in each server. For instance, it can be first-in first-out (FIFO), last-in first-out (LIFO), etc. There might also be single or multiple queues. The queue discipline that will be used in this research is FIFO with a single queue in all the process except the queue to the Nicaraguan customs process where two queues are available simultaneously.

In the case of “queue to migration in Costa Rica”, a 10 000 capacity was set even though the queue can be longer but it is not probable under normal circumstances.

TABLE 5.3.

Simulation I Input Data for Queues

Queue	Queue Capacity	Queue Characteristic
Queue to migration in Costa Rica	10000	FIFO
Queue #1 to customs in Costa Rica	1	FIFO
Queue #2 to customs in Costa Rica	1	FIFO
Queue #2 to customs in Costa Rica	1	FIFO
Queue to drug enforcement police in Costa Rica	100	FIFO
Queue to Costa Rican Gate in Costa Rica	1	FIFO

Queue	Queue Capacity	Queue Characteristic
Queue to fumigation in Nicaragua	10	FIFO
Queue to Police in Nicaragua	4	FIFO
Queue #1 to customs in Nicaragua	1	FIFO
Queue #2 to customs in Nicaragua	1	FIFO

Source. Own Elaboration based on the census data.

TABLE 5.4.

Simulation II Input Data for Queues

Queue	Queue Capacity	Queue Characteristic
Queue to migration in Costa Rica	10000	FIFO
Queue to Costa Rican Gate in Costa Rica	50	FIFO
Queue to fumigation in Nicaragua	10	FIFO
Queue to Police in Nicaragua	4	FIFO
Queue #1 to customs in Nicaragua	1	FIFO
Queue #2 to customs in Nicaragua	1	FIFO

Source. Own Elaboration based on the census data.

TABLE 5.5.

Simulation III Input Data for Queues

Queue	Queue Capacity	Queue Characteristic
Queue to migration in Costa Rica	10000	FIFO
Queue to Costa Rican Gate in Costa Rica	50	FIFO
Queue to fumigation in Nicaragua	10	FIFO
Queue #1 to Police in Nicaragua	4	FIFO
Queue #2 to Police in Nicaragua	4	FIFO
Queue #1 to customs in Nicaragua	1	FIFO
Queue #2 to customs in Nicaragua	1	FIFO

Source. Own Elaboration based on the census data.

5.5 Service time

The data recorded at each Costa Rican process was run in the ExpertFit software to determine the best distribution that fits the data. The distribution with the lowest square error was selected and imputed on the simulation.

TABLE 5.6 shows the descriptive statistics per process and

TABLE 5.7 shows the statistical distribution inputs and the number of servers. The latter refers to the number of stations that are available to fulfil the service. It can be single server (customers line up for a single bottleneck or station) or multi server (which are parallel servers where the same service is served by several servers).

The Peñas Blancas export process has eight different processes. All the Costa Rican processes are “single server”, except for the customs process, which have three servers. One customs server works from 6:00 to 00:00, the second server from 8:00 to 20:00 and the third server from 10:00 to 16:00. These working hours were considered in the simulation. The working hour of the Peñas Blancas land border post is from 6:00 to 00:00, every day.

TABLE 5.6.
Descriptive statistics of queues and processes in Peñas Blancas, in minutes

	Migration process	Customs process	Drug enfor. inspection	Gate inspection
Mean	0.3	2.8	2.1	0.4
Std. Error	0.0	0.6	0.1	0.0
Median	0.1	1.6	1.0	0.2
Mode	0.1	1.8	0.1	0.0
Std. Dev	0.7	23.9	3.3	0.9
Sample Variance	0.4	571.4	10.8	0.9
Kurtosis	328.3	1342.9	17.4	358.1
Skewness	14.0	36.2	3.6	15.3
Range	18.0	893.6	28.0	25.9

Minimum	0.0	0.0	0.0	0.0
Maximum	18.0	893.6	28.0	25.9
Sum	504.2	4094.2	3701.9	666.4
Count	1627	1441	1735	1624

Source. Own Elaboration based on the census data.

TABLE 5.7.

Simulation Input Data for Costa Rican Processes

	Distribution	Location	Scale	Shape 1/2	Number of servers
Migration	inversegaussian	0.016454	0.293431	0.066485	1
Customs	log logistics	0.0	1.624670	2.105173	3
Police	Pearson 6	0.016645	6.794330	0.718662	1
				3.278671	
Gate	Gamma	0.0	0.61030	0.64619	1

Source. Own Elaboration based on the census data.

In the case of the Nicaraguan process, mean time obtained from the Time Release Study performed by SIECA was used (SIECA, 2022). TABLE 5.8 displays the average processing time for import, transit, and empty trucks, as well as the number the number of servers per process. Based on historical data of the Nicaraguan Customs Administration, 46.9% of the trucks entering Nicaragua are transit, 33.8% are imports and 19.2% are empty trucks. In this sense, the simulation was programmed to the processing time based on the mean average and by percentage of each process. For example, 19.2% of the trucks entering Nicaragua have a mean time processing of 4.15 minutes for the fumigation and so on.

TABLE 5.8.

Simulation Input Data for Nicaraguan Processes, in minutes

	Import	Transit	Empty truck	Number of servers
Fumigation in Nicaragua	8.20	4.47	4.15	1*

Police in Nicaragua	8.25	4.42	4.40	1*
Migration in Nicaragua	3.33	3.17	2.98	1*
Customs in Nicaragua	6.05	3.75	4.68	2

Source. Own Elaboration based on [SIECA \(2022\)](#).

Chapter 6 | Simulation Results and Analysis

This thesis ran three simulations. Simulation I: The accumulation of vehicles under the existing traffic and operation conditions; Simulation II: The accumulation of vehicles under the existing traffic and with the new infrastructure and process; and Simulation III: The accumulation of vehicles under the existing traffic, with the new infrastructure and process, and an additional set of booth in Nicaragua from incoming trucks. These simulations were studied under current truck volumes obtained during the 7-day census. Data is recorded from each scenario and is analysed based on the Border Integration Program's measures of performance as well as other indicators related to throughput, stay time, states and content.

6.1 Border Integration Program performance measures

As explained in chapter 4 of this study, the success of the Border Integration Program is measured against several macro indicators. Three of these macro indicators were analysed using the results of the simulation:

1. Maximum cargo processing capacity of the border post (export), measured in terms of trucks per day. It refers to the number of trucks that have finished the customs controls of Costa Rica.
2. Average export border crossing cycle time measured in terms of minutes per truck. It refers to the time it takes from the moment it arrives to the first queue until it leaves the Costa Rican territory.
3. Average time spent in queue before starting the control processes, measured in terms of minutes per truck. It refers to the time spent in the migration process queue in Costa Rica.

The Border Integration Program's macro indicators do not include the performance of Nicaragua. However, these are important as they impact the Costa Rican performance. In this sense, TABLE 6.1 presents a summary of the macro indicators of the Border Integration Program for both Costa Rica and Nicaragua. The Nicaraguan macro indicators were calculated as follow:

1. Maximum cargo processing capacity of the border post (import), measured in terms of trucks per day. It refers to the number of trucks that have finished the customs controls of Nicaragua.
2. Average export border crossing cycle time measured in terms of minutes per truck. It refers to the time it takes from the moment it arrives to the first queue until it leaves the Nicaraguan territory.
3. Average time spent in queue before starting the control processes, measured in terms of minutes per truck. It refers to the time spent in the fumigation queue in Nicaragua.

Furthermore, TABLE 6.1 shows the average cycle time of Costa Rica and Nicaragua. This refers to the moment the truck arrives to the Costa Rican migration queue until it finishes the Nicaraguan Customs process. Lastly, the average queue time of Costa Rica and Nicaragua is the summatory of all the queues in both countries that a truck must undergo.

TABLE 6.1.
Summary of the Border Integration Program Performance Measurements, in minutes

Scenario	Max. truck exiting CR and NI		Ave. cycle time			Ave. queue time		
	In CR	In NI	In CR	In NI	CR+NI	In CR	In NI	CR+NI
Simulation I	203	192	1190.08	109.96	1300.04	612.73	67.96	680.69
Simulation II	203	192	1251.64	110.55	1362.19	806.97	68.69	875.66
Simulation III	315	303	195.66	52.84	248.5	169.64	23.30	192.94

Source. Own Elaboration based on the simulation results.

Based on the results of the macro indicators, it is possible to note that between Simulation I and II, there is no significant change in the Nicaraguan results, however, the average cycle time and queue time increased significantly in Costa Rica, especially the average queue time (from 612.73 minutes to 806.97, which represents a 24% increase). Simulation III has the best performance in all three macro indicators for both countries. There is a 58% increase of trucks exiting Nicaragua, the average cycle time for both countries reduced from 1300.04 minutes (Simulation I) and 1362.19 minutes (Simulation II) to 248.5 minutes and the average queue time in Simulation III is 22% of Simulation II.

6.2 Analysis of Simulation Outputs

The individual Simulation results are presented in Appendices C of this thesis. This section analyses the results of the three simulations by comparing the outcomes.

The truck arrivals are the same in the three simulations, what varies are the number of trucks that have finalised all the Costa Rican and Nicaraguan processes (outputs). TABLE 6.2 shows the comparison between the number outputs in each simulation. Two different scenarios were made for Simulation I. The first one does not have a temporary extra lane opened in Nicaragua for the fumigation, police and migration processes while the second one has a such temporary lane available from 12:00 midday to 00:00 midnight on Thursday. The temporary extra lane is simulated here because based on the performed interview to the Peñas Blancas border coordinator, mostly on Thursdays, the Costa Rican customs authority seeks help from the Nicaraguan authorities to open an extra server for fumigation, police, and migration. These extra servers are opened when agreed between the customs authorities of Costa Rica and Nicaragua. They are not open all the time because these extra servers are used for the export process of Nicaragua.

When comparing Simulation I.a, and Simulation II, there is no change whatsoever on the number of outputs. Temporarily opening an extra lane in Nicaragua increases the total output by 9.1% (126 additional trucks). Even though with Simulation I.b there is an increase of outputs, all the comparisons in this section will be made with Simulation I.a. because the opening on an extra lane in Nicaragua is dependent on the agreement of such country.

Simulation III is the best performing in terms of total outputs per day. The outputs increased by more than 25.3%, which represents 348 trucks.

TABLE 6.2.
Accumulated Trucks' outputs per day, per Simulation

Day	Truck arrivals	Trucks outputs			
		Simulation I.a	Simulation I.b	Simulation II	Simulation III
Day 1	284	187	187	187	270
Day 2	575	374	374	374	573
Day 3	806	561	561	561	804
Day 4	1011	753	871	753	1008
Day 5	1128	939	1065	939	1125
Day 6	1429	1124	1250	1124	1426
Day 7	1888	1377	1503	1377	1725

Source. Own Elaboration based on the simulation results.

Furthermore, based on the TABLE 6.2, it seems that the new infrastructure of the Peñas Blancas land border post does not affect positively or negatively the total output. However, it increases the length of the queue to migration in Costa Rica.

TABLE 6.3 shows the number of trucks accumulated in day 7 for each queue per simulation. Simulation I has approximately 7.7 kilometres of trucks parked in the Interamerican Highway in Costa Rica while Simulation II has almost 8.8 kilometres. There is an increase in the length of the queue with the new blueprint because there are queues that disappear with the new infrastructure and the lodging capacity of each queue has also reduced. For instance, six queues have disappeared from Simulation II. In the Simulation I, 104 trucks can be absorbed in the Costa Rica side after the Costa Rican migration process; in the Simulation II, the number of trucks that can be lodged after the Costa Rican migration process reduces to 50, which means that the additional 54 trucks must wait in the first queue because it has “unlimited” capacity.

From Day 1 to Day 6 of Simulation III the “queue to migration in CR” has been mostly empty; on Day 7 such queue had 132 trucks, which represents around 2.6 kilometres, Day 7 is the day with the highest arrival rate and most of them arrived nearly at the end of the working hours.

FIGURE 6.1 and

FIGURE 6.2 shows a comparison of the Costa Rican servers' and queues' state in each simulation, respectively. There are five states, two applicable to queues (empty and releasing) and three to processes (idle, processing and blocked). "Empty" means that there are no contents/trucks waiting in the queue and "releasing" occurs when trucks arrive to the queue and sent to a server. Regarding the states of the servers, "idle" means that they are waiting for a content/truck to arrive, in other words, in this state, the servers are not working. "Processing" occurs when the server is performing the assigned process. "Blocked" means that the server has finished performing the task or process (in other words the "processing" state has finished), but the content/truck cannot move forward because the next step (which can be a queue or another server) cannot receive the truck as it is full or occupied at that time.

The states of all the Nicaraguan queues and servers are the same in Simulation I and II because no changes in Nicaragua were introduced in Simulation II.

With regards to the servers' state in Costa Rica, Simulation II has a substantial increase of blockage because in this scenario there is no change in the Nicaraguan side and the subsequent queues were either eliminated (such as the queue to police) or the queue capacity has changed as mentioned before (from 104 queue capacity to 54). In Simulation II, three out of six servers are blocked 86% of the time, the other three are blocked between 77% and 74% of the time. All six servers are "idle" approximately 13% of the time and the "processing" time varies from 1% (for migration) to 15% (for customs). The increase in the blocking time is due to the impossibility of trucks to move forward to the Nicaraguan steps. In other words, this blockage reveals that the Nicaraguan capacity is an important bottleneck.

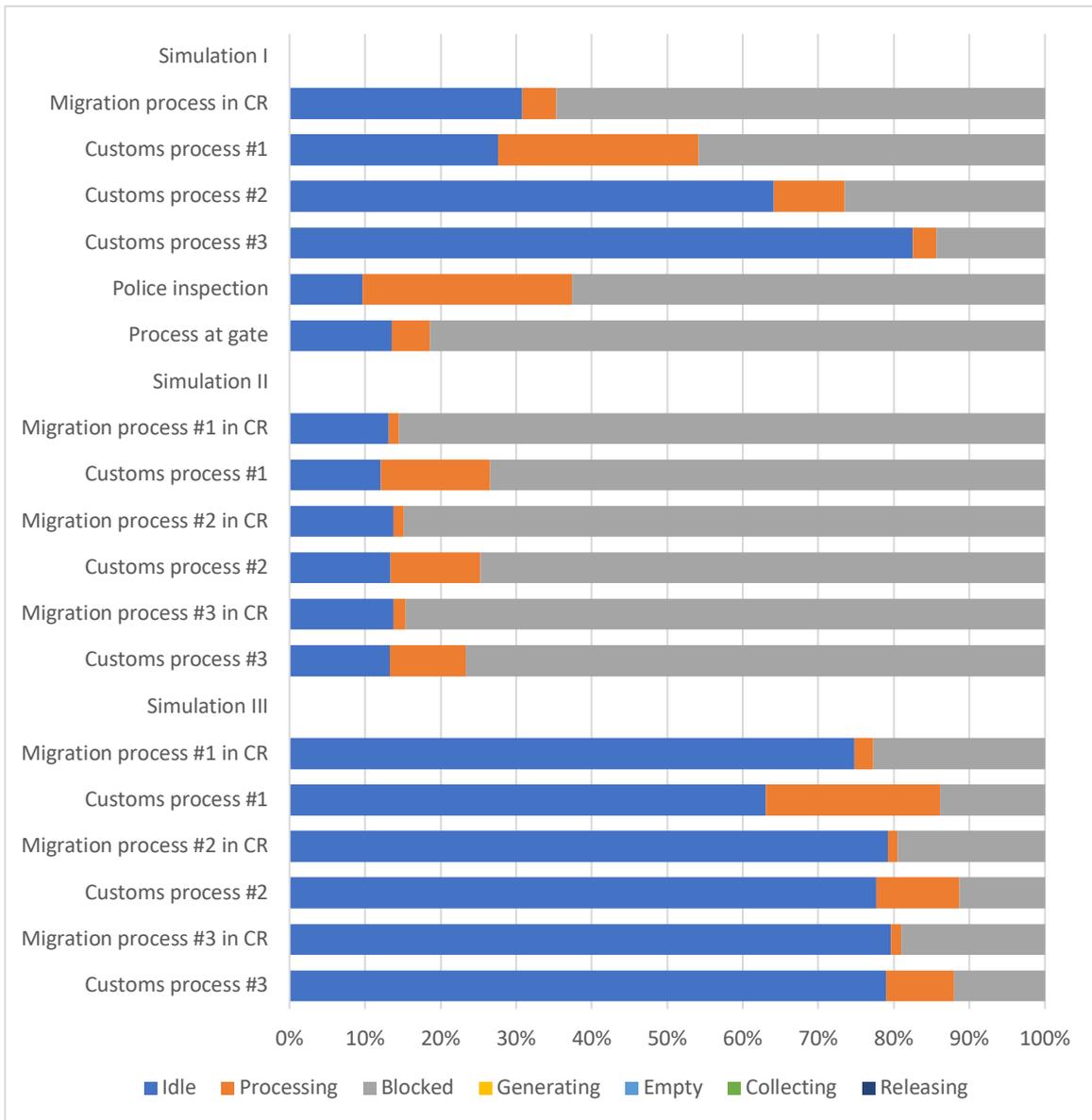
In Simulation III, a permanent additional lane is added for the fumigation, police and migration process of Nicaragua. In this scenario, the blockage time has reduced significantly from an 86% blockage in the migration process on Simulation II, it has reduced to 23% and customs process blockage from 77% to 14%. The "block" status is also reduced in the Nicaraguan side. For example, the Nicaraguan customs process "block" status changed from 16% to 7.5%.

The total percentage of time of the three Costa Rican customs process booths in the state of "processing" reduced from 39% to 36%. The "idle" time in Simulation III has also increased in

the three migration and customs booths in the Costa Rican side. In this sense, it might be sufficient to have only one or two booths opened instead of having three, this way, the “processing” state increases while the “idle” time decreases.

FIGURE 6.1.

Costa Rican server’s state in each simulation, in minutes



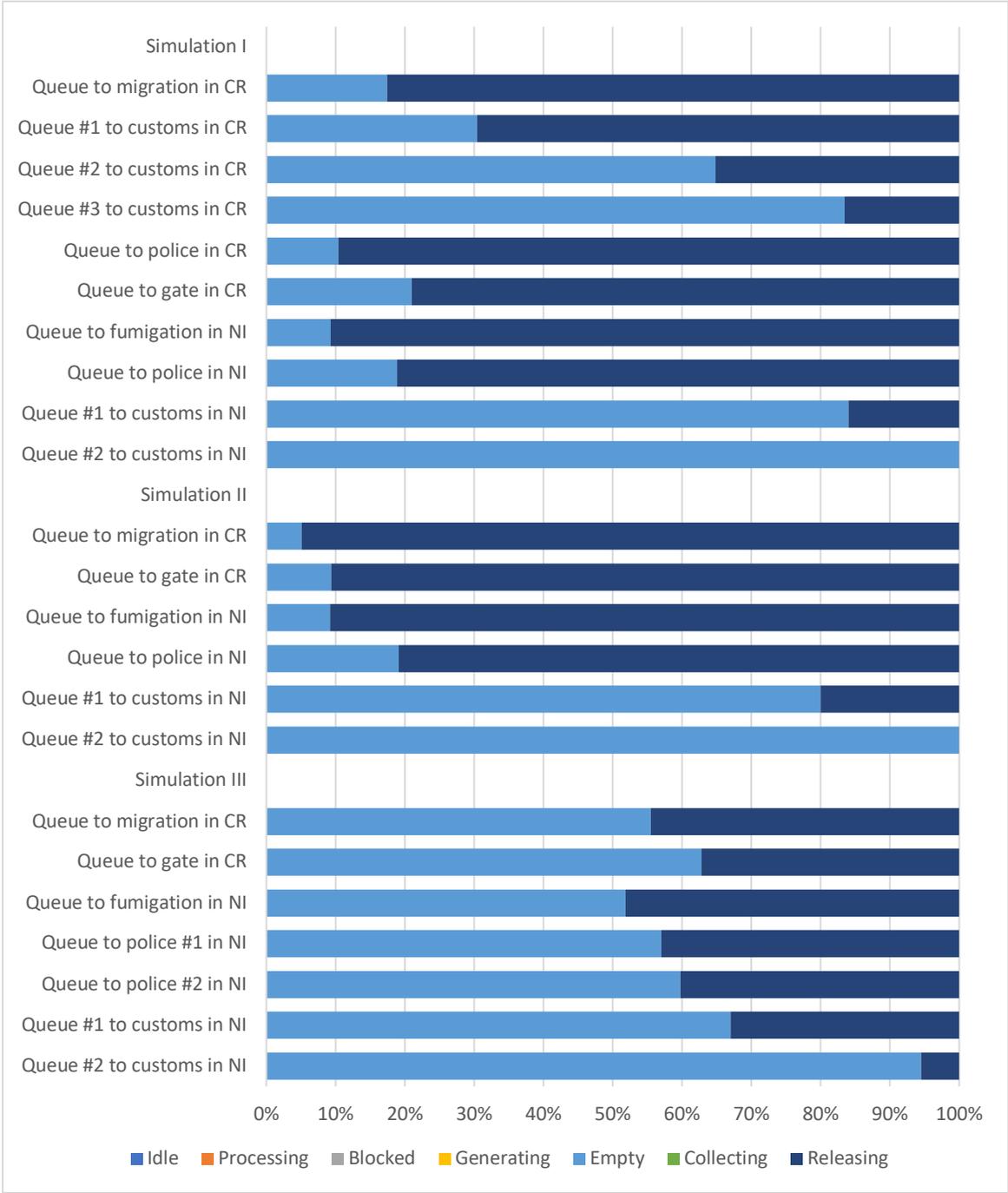
Source. Own Elaboration based on the simulation results.

The

FIGURE 6.2 shows the states of each queue. Simulation I has a larger number of queues. With the new infrastructure the processes and queues are optimized, that is why less queues are present. In Simulation I, Queue #1 and #2 to Customs in Nicaragua are mostly empty because the booths are not always opened. The queues after the Costa Rican customs process are basically full all the time because the Nicaraguan import processes are not able to absorb the trucks at the same rate as they conclude the Costa Rican export process.

FIGURE 6.2.

Costa Rican and Nicaraguan queues' state in each simulation, in minutes



Source. Own Elaboration based on the simulation results.

In the three scenarios the queue #1 and #2 of the Nicaraguan customs are mostly empty because the bottleneck are the processes before customs, therefore, once the trucks finish the migration process, they move directly towards the Nicaraguan customs process without the need to stop by the queue.

Queues at Simulation II are mostly full because the number of queues and maximum content were reduced. Principally all the Costa Rican queues were occupied to the maximum level as well as the “queue to fumigation in NI”.

Simulation III shows that most of the queues are empty. This is possible because with the additional permanent lane to perform the fumigation, police and migration processes of Nicaragua, allowed to increase the absorption of trucks to perform the Nicaraguan import process. In other words, Nicaragua is able to cope with the number of trucks that Costa Rica authorised for export.

TABLE 6.3 presents the number of trucks accumulated on Day 7 on each simulation at each queue.

The total number of trucks waiting in Costa Rica in Day 7 did not vary between Simulation I and II, what varies is the distribution of the trucks. Because Simulation II eliminates queues and the maximum capacity of the queues changed, most of the trucks are present in the “queue to migration in CR”.

Simulation III has the lowest number of trucks waiting in Day 7. From Day 1 to 6, practically there are no trucks waiting in the “queue to migration in CR” on Simulation III. In Day 7 there are 132 trucks because that day has the highest interarrival trucks and they arrived near the closing of the border post.

When considering only the “queue to migration in CR”, between Simulation I and II, there was an increase of trucks in Simulation II by 13.4%. Between Simulation II and III there was a reduction by 69.9% of such queue. And, between Simulation I and III, there was a reduction of 65.9%.

Regarding the queues on the Nicaraguan side, the total number of trucks waiting in Nicaragua did not vary at all between Simulation I and II. When it comes to Simulation III, there was a reduction of 1 truck on the total number of trucks even though an additional queue was created.

TABLE 6.3.
Number of trucks accumulated on day 7 of each simulation, per queue

Queue	Simulation I	Simulation II	Simulation III
-------	--------------	---------------	----------------

Queue to migration in CR	387	439	132
Queue #1 to customs in CR	0	N/A	N/A
Queue #2 to customs in CR	0	N/A	N/A
Queue #3 to customs in CR	1	N/A	N/A
Queue to police in CR	100	N/A	N/A
Queue to gate in CR	1	50	7
TOTAL QUEUE ON DAY 7 IN CR	489	489	139
Queue to fumigation in NI	10	10	10
Queue #1 to police in NI	2	2	0
Queue #2 to police in NI	N/A	N/A	1
Queue #1 to customs in NI	1	1	1
Queue #2 to customs in NI	0	0	0
TOTAL QUEUE ON DAY 7 IN NI	13	13	12
TOTAL QUEUE ON DAY 7	502	502	151

Source. Own Elaboration based on the simulation results.

The

TABLE 6.4 below show the stay time of each queue. Stay time in queues is measured from the moment the truck arrives until it leaves the queue. In some cases, there are one, two or three queues for a same process, so, the total stay time has several paths. The footnote of each total explains how the data was obtained.

Simulation I have the longest total stay time in queues with 20.8 hours (1249.29 minutes), followed by Simulation II with 20.3 hours (1215.45 minutes). Simulation III has a substantially lower time with 4.6 hours in average (272.85 minutes).

Simulation II has the longest stay time in the first queue, which is the queue to migration in CR. In average, it takes 13.5 hours, followed by Simulation I with an average of 10.3 hours. Simulation II has a longer stay time in such queue because of the difference of trucks that can be absorbed in the subsequent queues. In Simulation I, excluding the “queue to migration in CR” and the queues in Nicaragua, it is possible to absorb 104 trucks while Simulation II can only absorb 54 trucks.

The stay time in the queues of Nicaragua are similar between Simulation I (86.77 minutes) and II (87.22 minutes). For Simulation III, the Nicaraguan stay time also reduces to 14.09 minutes (using Queue #1 to customs in NI) 45.49 minutes (using Queue #2 to customs in NI).

TABLE 6.4.
Average stay time of trucks per queue, per simulation, in minutes

	Simulation I	Simulation II	Simulation III
Queue to migration in CR	612.73	806.97	163.64
Queue #1 to customs in CR	7.11	N/A	N/A
Queue #2 to customs in CR	9.09	N/A	N/A
Queue #3 to customs in CR	11.68	N/A	N/A
Queue to police in CR	534.55	N/A	N/A
Queue to gate in CR	5.95	321.25	23.30
	1160.34^a		
TOTAL QUEUE TIME IN COSTA RICA	1162.32^b	1128.22	186.94
	1164.91^c		
Queue #1 to fumigation in NI	67.96	68.69	10.32
Queue #1 to police in NI	17.52	16.93	2.85
Queue #1 to customs in NI	1.29	1.60	0.92
Queue #2 to customs in NI	0.00	0.00	11.87
Queue #2 to police in NI	N/A	0.00	23.30
			14.09^d
TOTAL QUEUE TIME IN NICARAGUA	86.77	87.22	45.49^e
	1247.11^f		
TOTAL STAY TIME IN QUEUE (CR+NI)	1249.09^g	1215.45	273.03ⁱ

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^a Summatory using Queue #1 to customs in CR

^b Summatory using Queue #2 to customs in CR

^c Summatory using Queue #3 to customs in CR

^d Summatory using Queue #1 to customs in CR

^e Summatory using Queue #2 to customs in CR

^f Summatory using Queue #3 to customs in CR

^g Summatory using Queue #1 to customs and police in NI

ⁱ Summatory using Queue #1 to customs and police in NI

	Simulation I	Simulation II	Simulation III
	1251.68 ^h		272.66 ^j

Source. *Own Elaboration based on the simulation results*

TABLE 6.5 shows the stay time of each process or inspection. Because in some cases there are one, two or three servers performing the same type of process, the sum of the total stay time in the Costa Rica and Nicaraguan side has several paths. The footnote of each total explains how the data was obtained. Stay time in processes or inspection are not equivalent to the time it takes to conclude the process or inspection. The process or inspection starts once the truck arrives to the server, however, once the process or inspection has concluded, it is possible that the server stays “blocked” because the truck cannot move on to the next stage as it might be occupied.

The total stay time in the Nicaraguan process have insignificant variations when comparing the three simulations.

In terms of processes and inspection of Costa Rica, Simulation II has the worst performing stay time and Simulation III the best performing stay time among the three simulations. In average, Simulation I takes 27.6 minutes; Simulation II 36.2 minutes and Simulation III 8.7 minutes.

TABLE 6.5.
Average stay time of trucks per process or inspection, per simulation, in minutes

	Simulation I	Simulation II	Simulation III
Migration process #1 in CR	4.58	17.95	2.85
Customs process #1 in CR	7.38	18.23	4.19
Migration process #2 in CR	N/A	17.63	4.53
Customs process #2 in CR	9.28	17.78	4.85
Migration process #3 in CR	N/A	18.39	4.77
Customs process #3 in CR	12.36	18.59	4.94
Police inspection in CR	6.79	N/A	N/A

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^h Summatory using Queue #2 to customs and police in NI

^j Summatory using Queue #2 to customs and police in NI

Chapter 6 | Simulation Results and Analysis

	Simulation I	Simulation II	Simulation III
Process at gate in CR	6.52	N/A	N/A
	25.26^{k1}	36.18ⁿ⁴	7.04^{q7}
TOTAL STAY TIME IN CR PROCESS	27.17^{l2}	35.41^{o5}	9.38^{r8}
	30.25^{m3}	36.98^{p6}	9.74^{s9}
Fumigation process #1 in NI	6.97	6.98	6.95
Police process #1 in NI	6.97	6.98	7.04
Migration process #1 in NI	3.72	3.86	4.17
Customs process #1 in NI	6.03	6.03	5.64
Customs process #2 in NI	5.00	5.00	5.62
Fumigation process #2 in NI	N/A	N/A	6.32
Police process #2 in NI	N/A	N/A	6.45
Migration process #2 in NI	N/A	N/A	3.91
	23.70^{t10}	23.85^{v12}	23.80^{x14}
TOTAL STAY TIME IN NI PROCESS	22.67^{u11}	22.81^{w13}	22.29^{y15}

Source. Own Elaboration based on the simulation results.

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^k Summatory using customs process #1 in CR

^l Summatory using customs process #2 in CR

^m Summatory using customs process #3 in CR

ⁿ Summatory using migration and customs process #1 in CR

^o Summatory using migration and customs process #2 in CR

^p Summatory using migration and customs process #3 in CR

^q Summatory using migration and customs process #1 in NI

^r Summatory using migration and customs process #2 in NI

^s Summatory using migration and customs process #3 in NI

^t Summatory using customs process #1 in NI

^u Summatory using customs process #2 in NI

^v Summatory using customs process #1 in NI

^w Summatory using customs process #2 in NI

^x Summatory using fumigation, police, migration and customs process #1 in NI

^y Summatory using fumigation, police, migration and customs process #2 in NI

Chapter 7 | Conclusions and recommendations

This final chapter opens with a summary of the main research findings. It proceeds to discuss the implications of the study beyond the immediate research context for both the academia and the practical implications. Next, the chapter elaborates on the limitations of the thesis and concludes with recommendations on future research topics and methodological considerations for future research.

7.1 Summary of Findings

The research question that guided this thesis is the following: “By what method can a design be evaluated in resolving a congested truck load export process?”. To answer this research, question the Border Integration Program is used as a case study. This program has developed a blueprint for the new infrastructure of the Peñas Blancas land border post. It is expected that this project will cost around 45 million USD. Peñas Blancas is the most utilized land border post in Costa Rica, and it is known for its kilometeric queues that could go up to 15 kilometres in any given day.

This thesis proposes the use of Discrete Event Simulation (DES) using the FlexSim’s 3D program to simulate three scenarios based on real data collected during a 10-day census. The three scenarios are:

- Simulation I analysed the Peñas Blancas Land Border post under the existing traffic and operation conditions.
- Simulation II analysed the Peñas Blancas Land Border post under the existing traffic but with the new infrastructure and process based on the blueprint developed by the Border Integration Project of Costa Rica.

- Simulation III is the same as in Simulation II with an additional lane in Nicaragua to process the incoming trucks. Such additional lane contains the following processes: fumigation, police inspection and migration.

Data is recorded from each scenario for 7 days and indicators related to throughput, stay time, states and content were obtained for each queue and server.

Based on the results of the case study, it was possible to determine that DES using FlexSim was appropriate to understand the “what is going on” with the “as is” process and to evaluate “what if” scenarios without changing the real world.

The main findings of the simulations were:

- The new infrastructure will not improve the current congestion problem in the Interamerican Highway in Costa Rica. The simulation shows that the new infrastructure of the Peñas Blancas land border post increases the length of the queue to migration in Costa Rica. In day 7, Simulation I has approximately 7.7 (387 trucks) kilometres of trucks parked in the Interamerican Highway in Costa Rica while Simulation II has almost 8.8 kilometres (439 trucks). When adding a new lane in the Nicaraguan process, from Day 1 to 6, “queue to migration in CR” has been empty, while Day 7 such queue had 132 trucks, which represents around 2.6 kilometres, Day 7 is the day with the highest arrival rate and most of them arrived nearly at the end of the working hours. In other words, when considering only the “queue to migration in CR”, between Simulation I and II, there was an increase of trucks in Simulation II by 13.4%. Between Simulation II and III there was a reduction by 69.9% of such queue. And, between Simulation I and III, there was a reduction of 65.9%.
- The new infrastructure will not improve the total output of trucks because the Nicaraguan process is the bottleneck, therefore, even if Costa Rica improves the infrastructure or optimizes the processes, if Nicaragua is not able to absorb the incoming trucks, Costa Rica will remain as the parking lot of Nicaragua’s import process. Simulation I and II have the same number of outputs (1377 trucks). With Simulation III, the outputs increased by more than 25.3%, which represents 348 additional trucks.
- The new infrastructure will not improve the efficiency of the servers. Simulation II has a substantial increase of blockage when compared to Simulation I. In Simulation II, three out of six servers are blocked 86% of the time, the other three are blocked

between 77% and 74% of the time. All six servers are “idle” approximately 13% of the time and the “processing” time varies from 1% (for migration) to 15% (for customs). The increase in the blocking time is due to the impossibility of trucks to move forward to the Nicaraguan steps. When adding an extra lane in Nicaragua, Simulation III shows that the blockage time has reduced significantly from an 86% blockage in the migration process on Simulation II, it has reduced to 23% and customs process blockage from 77% to 14%. The “block” status is also reduced in the Nicaraguan side. For example, the Nicaraguan customs process “block” status changed from 16% to 7.5%.

The above findings (with the corresponding supportive data) were presented to the Border Integration Program and the IADB. The Program and the Bank have acknowledged the importance of using simulation tools to evaluate potential impacts on what has been design in the infrastructure blueprints before building it. As a result of the findings of the simulations, actions have been set to evaluate the blueprint and activate discussions with Nicaragua.

7.2 Implications of the Study

7.2.1 Implications for Theory and Knowledge

This thesis has broadened the empirical scope of queueing theory to truck congestion at land border post context and the use of DES with real-life data to evaluate proposals or designs to solve the congestion problem.

In short, the main contribution of this thesis to the academia is that the use of DES with census data is important to accurately represent the “as is” situation and then, test the new design or designs using the same interarrival time and servers’ processing time to properly identify bottlenecks and compare the situations.

During the performed literature review, only three academic articles were found to be directly linked to the desired context of land border posts. Most of the articles, although some related to truck congestion, were set in a seaport context - see, e.g., [Chen et al. \(2011\)](#), [Chen et al. \(2013\)](#), [Chen & Jiang \(2016\)](#) and [Ma et al., \(2019\)](#).

Two out of the three research papers found in the context of land border posts did not address the research question studied in this thesis. For instance, [Ashur et al. \(2001\)](#) models

an expected problem with limited data set to define the distribution's parameters in the simulation. The study at hand proposed the use of simulation to solve a current problem using real life data collected through census or primary information to accurately identify distributions parameters.

The work of [Suttishe et al. \(2019\)](#) have a totally different scope from the present thesis. The aim of such study is to calculate the cost of service and to do so, the authors ran an ABC model simulation. This thesis does not aim to calculate the cost of service but rather estimate the truck congestion on queues and the evaluation of a blueprint design.

With regards to the work of [Haughton & Sapna Isotupa \(2012\)](#), the authors explored the design of scheduling system's performance using the Canadian-US border crossing as an example. They ran simulations based on empirical sources to estimate the parameters of the simulation. The study at hand also tries to evaluate the performance of a new design, so instead of evaluating a scheduling system, this thesis evaluates if the new layout of the infrastructure and processes proposed by the Border Integration Project of Costa Rica can impact the truck waiting time and congestion. This thesis differs from [Haughton & Sapna Isotupa \(2012\)](#) on the usage of census data and the modelling of the "as is" situation before modelling the new design.

7.2.2 Practical Implications

The main findings of this thesis can be applicable to multiple actors, including, policy makers in charge of introducing general measures needed to improve or solve an issue; designers, officers or consultant tasked to proposed specific solutions; international banking organization or the like that provide loans, grants or similar; among others.

The use of DES tools can be used by policymakers to understand the potential impact that the idea or plan that they are promoting or have in mind can impact the status quo. Since policies are not law but rather a plan that the government or business should follow, it makes sense that certain new policies should be simulated before deploying extensive and expensive resources. For example, the President of Costa Rica has recently announced to the public in general that he is planning to deploy scanners in all the maritime, land and air border post to scan 100% of the incoming and outgoing containers. This policy will certainly affect the efficiency of the Peñas Blancas land border post and will increase the queue at the

Interamerican highway. The use of the simulation tool proposed in this thesis helps to evaluate the impact of such policy design and present the results of such impact visually.

DES tools are also useful to those in charge of converting a policy into a feasible outcome. For example, simulations could be run on multiple blueprints to determine whether the desired impact will be achieved or not once the project concludes. Simulations can also help to identify the real bottleneck that might have not been identified at the beginning.

International or national organizations that provide loans, grants or similar, should use simulation tools to measure the impact of a project or policy before approving the expenditure or disbursement of a design.

7.3 Limitations

During the research process, two main limitations were encountered.

The first is the lack of access of data related to the Nicaraguan processes. To perform the simulation model, the researcher used the average time of the processes published in the Regional Time Release Study carried out by the Central American Economic Integration Secretariat in 2022 (SIECA, 2022).

The second research limitation was information related to the arrival of the trucks to the Peñas Blancas land border post. Such land border post operates from 6:00 am to midnight, however, trucks may arrive anytime. The 10-day census that was performed in February 2022 collected the truck arrival time from 6:00 am to 7:00 pm. Therefore, trucks that arrived outside such timeframe are not available. The pollsters asked the truck drivers the approximate time of arrival of the truck to the queue.

7.4 Recommendations

7.4.1 Future Research Topics

This research focused on trucks that did not require any physical inspections by any authority. However, physical inspections do take place in a real context. Therefore, future research could try to model additional scenarios that include documentary and physical inspections.

This work analysed the outgoing trucks from Costa Rica to Nicaragua. The new infrastructure that is designed for the Peñas Blancas land border post also processes incoming trucks to Costa Rica from Nicaragua. Therefore, to have a complete scenario of the impact of a new infrastructure, future research should include the incoming flow of trucks to Costa Rica.

This research models a new physical infrastructure blueprint, and the recommendation is also focused on incrementing a physical lane in the Nicaraguan side to reduce congestion. However, future research can focus on modelling the introduction of software or IT systems that might improve the processing time of the servers. In other words, new physical infrastructure is not necessarily the only solution to the congestion problem.

7.4.2 Recommendations Derived from Methodological, Research Design, or other Limitations of the Study

To have a more accurate simulation on land border posts, future research should try to collect data, via census, on both the importing and exporting country. On seaport simulations there is no need to model the process of the incoming country because of the distance between the ports. However, in the case of land, the process of one country usually has a direct impact on the counterpart because they are usually located immediately one next to the other. So, only modelling one side of the equation for land border post would be a mistake.

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Appendices A | Flexsim Simulation tool

This simulation is run using the Flexsim software. To understand how the Flexsim model simulation works, it is important to know the three main components that are present in the simulations. The following describes the component used in the simulation and Table B.1 shows the image of how these objects are visualized in the Flexsim software:

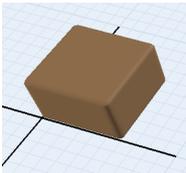
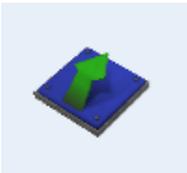
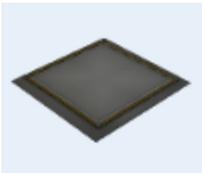
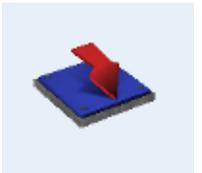
- **Flow items.** They are typically represented by physical components that flow through the process. These items are the ones that causes events. In this research, the flow items are trucks that are exiting Costa Rica through the Peñas Blancas land border post.
- **Objects.** They typically represent a physical location or resource that are needed to interact with the flow items or other objects. These objects define system behaviours. The objects are classified into two: (i) fixed resources²⁶ and (ii) task executors²⁷. All the objects used in in this research are the following fix resources:
 - **Source:** this is the object “used to create the flow items that travel through a model. [...] Sources can create flow item per an inter-arrival rate, per a scheduled arrival list, or simply from a defined arrival sequence”. This object has no inputs capabilities because they are the ones who create the flow items and release them to other objects, therefore, only outputs can be registered.
 - **Queue:** they are naturally occurring events that happen when flow items arrive faster than they can be processed. This object “is used to store flow items when a downstream object cannot accept them yet.” (Flexsim, 2022b). The simulation in this research contains several queue objects.
 - **Processor:** this object represents the forced time delay on the flow item (Flexsim, 2022a) . Several processors are used in the simulations, each one of these objects represents the process of a border agency.
 - **Sink:** This is the object “used to destroy flow items that are finished in the model. Once a flow item has travelled into a sink, it cannot be recovered. Any data collection involving flow items that are about to leave the model should be done either before the flow item enters the sink or in the sink's On Entry trigger”. There

is only one sink object in the simulation. Because the sink destroys the flow items it does not have any logic output. (Flexsim, 2022c)

- **Port connections.** Once the objects are defined, these port connections allow to determine the communications and coordination amongst them. There are two types of port connections:
 - Output-to-input port connections. They define possible flow items route to and from the fixed resources mentioned previously. These are the port connections used in this research.
 - Center ports. These used to point a task executer for the movement of a flow item from one place to another. These connections are not used in the current research because no task executer is needed in the model.

TABLE A.1.

Composition of the sample

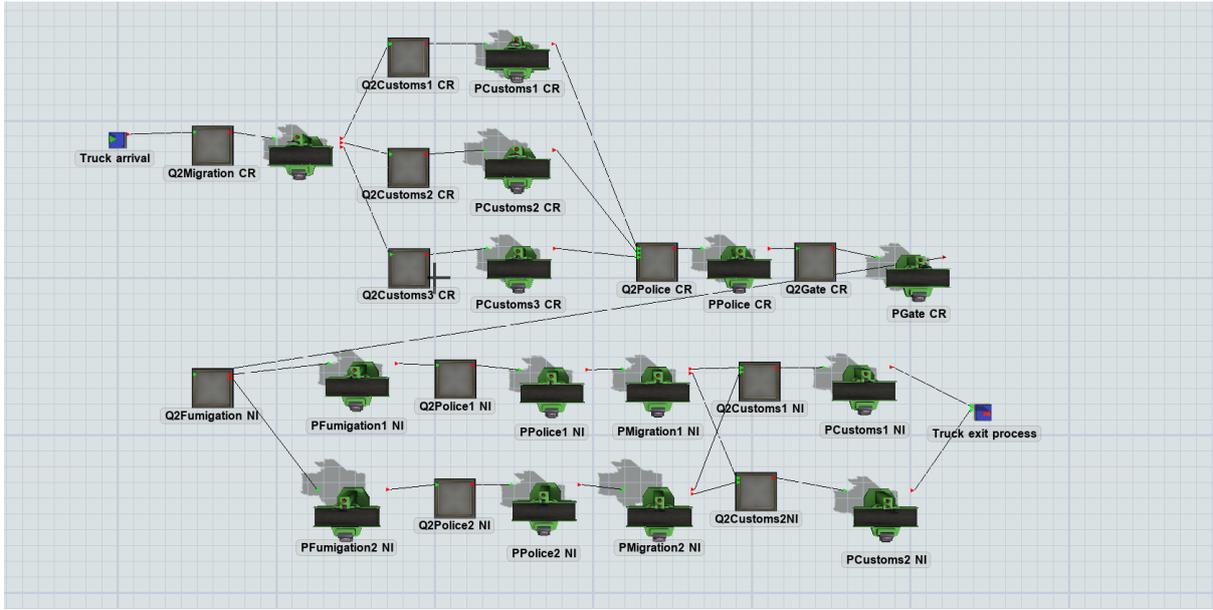
Simulation components in Flexsim				
Flow item	Source	Queue	Processor	Sink
				

Source. *Own Elaboration based on Flexsim software.*

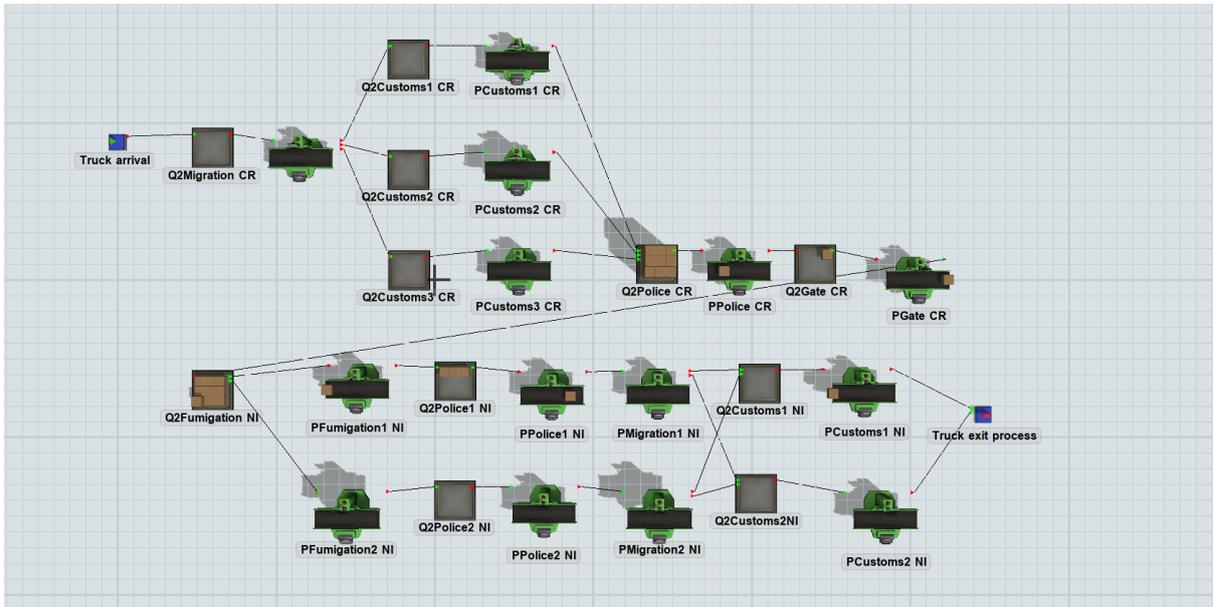
Appendices B | Simulation visuals

Simulation I

Servers and queues distribution

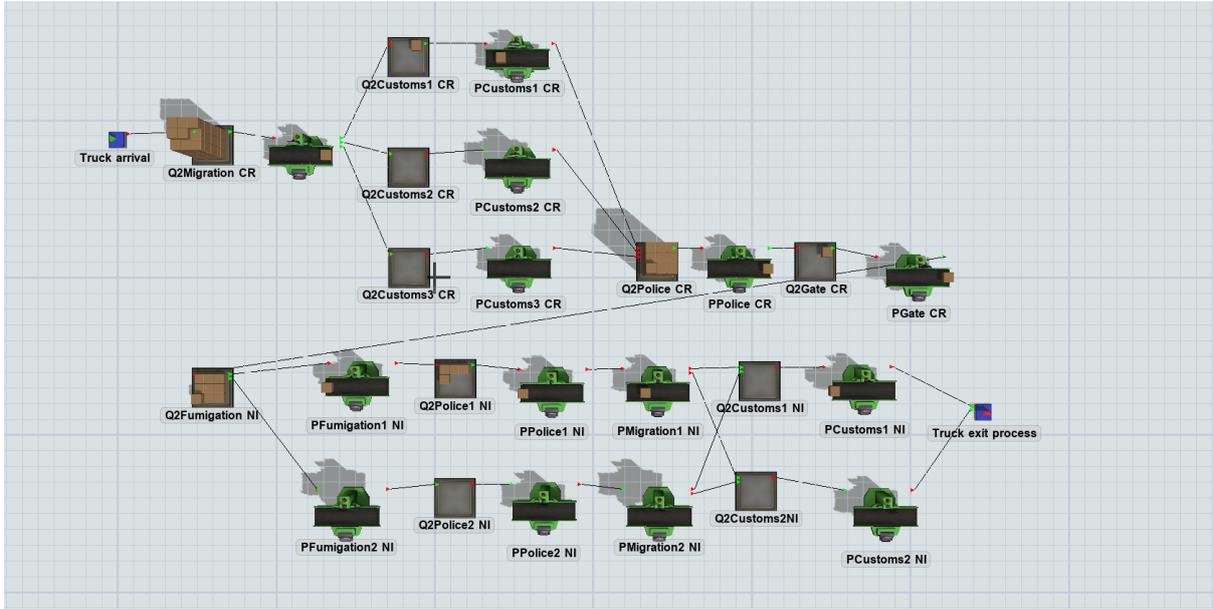


Day 1

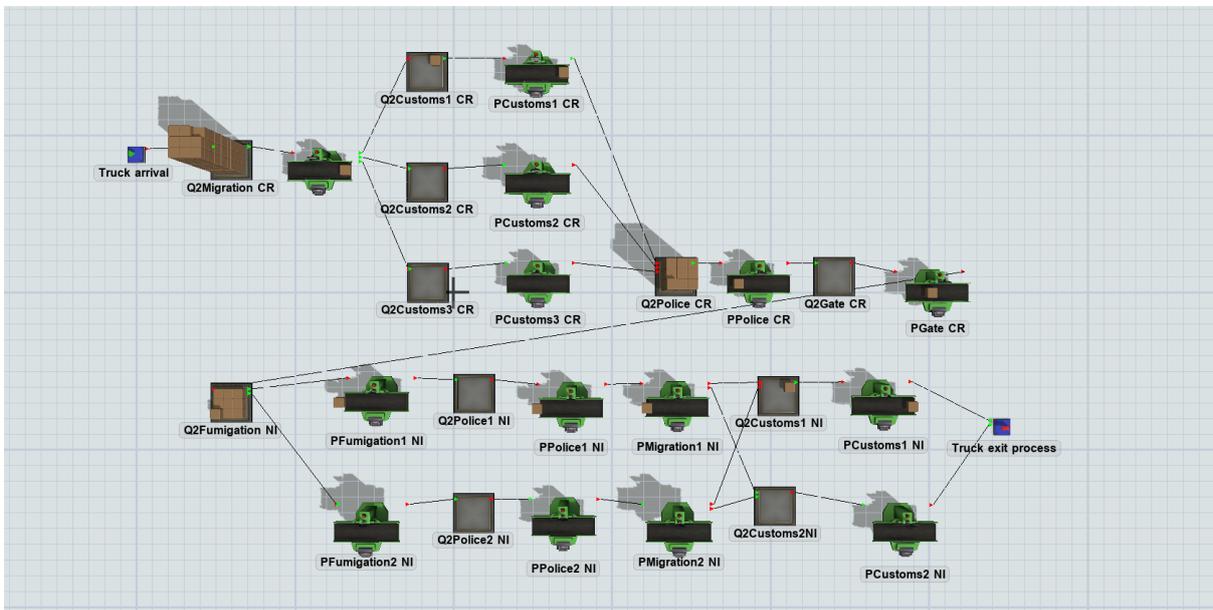


Appendices B | Simulation visuals

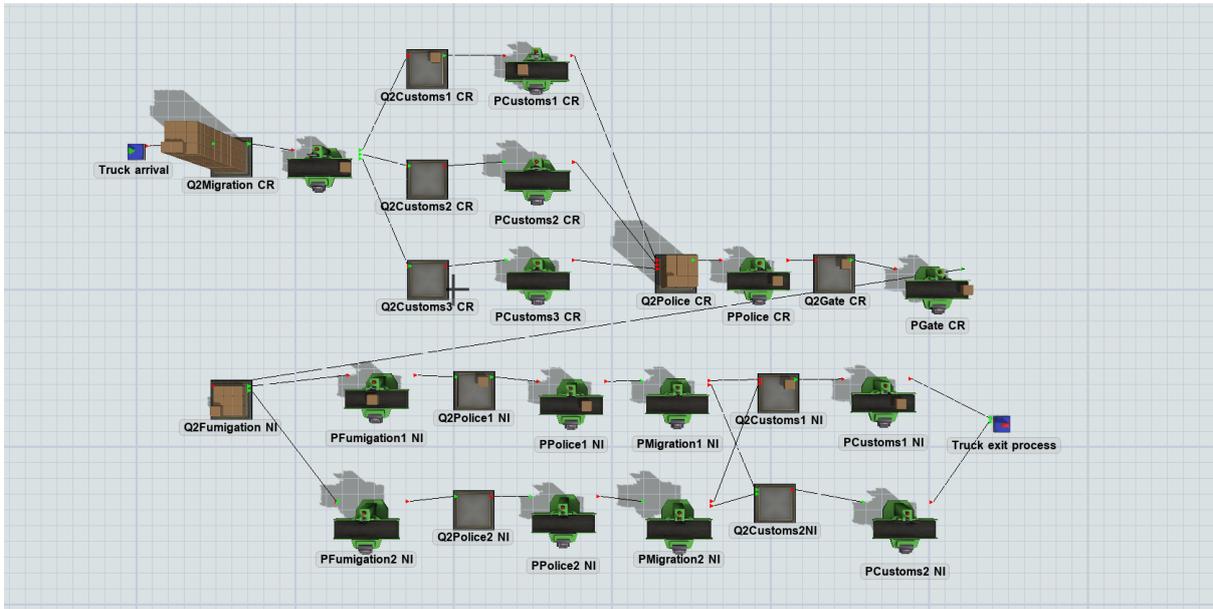
Day 2



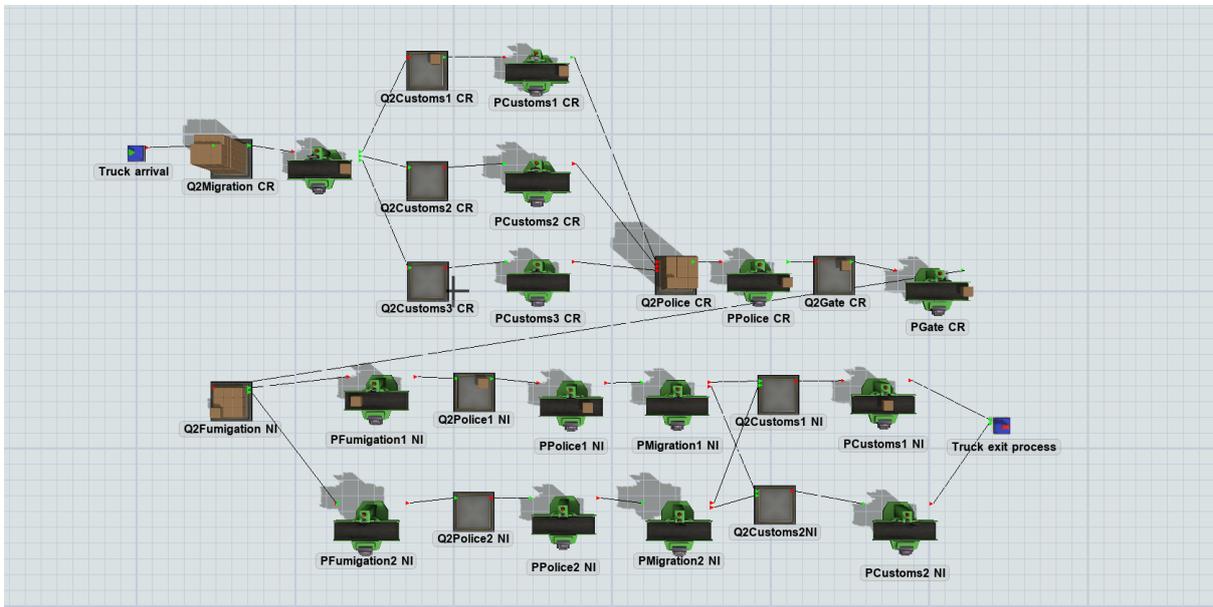
Day 3



Day 4

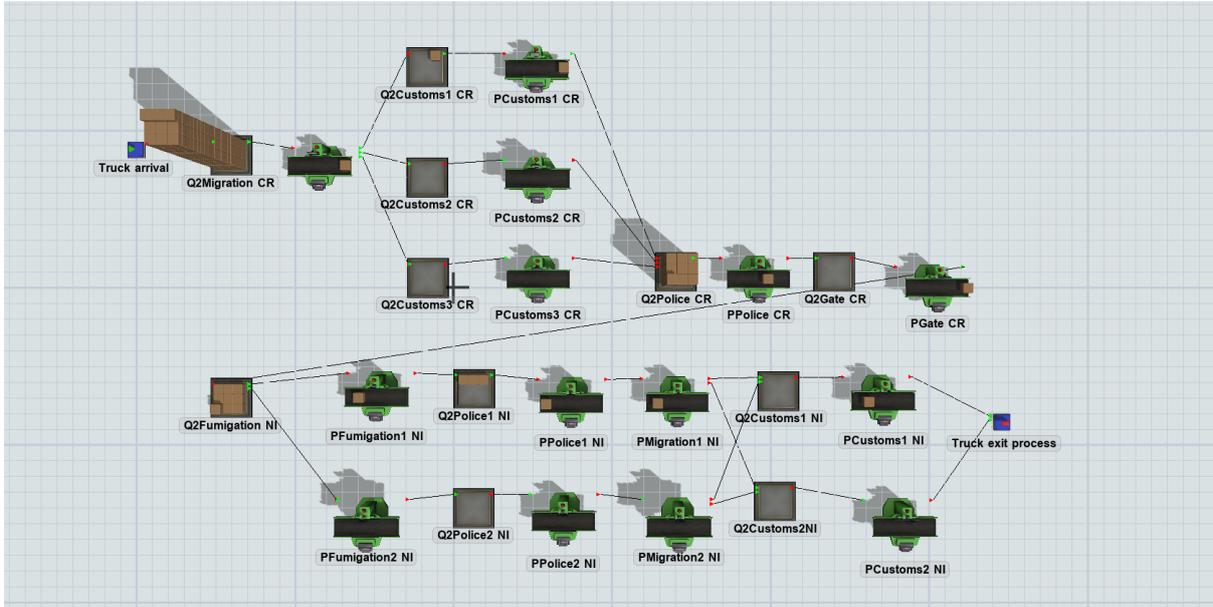


Day 5

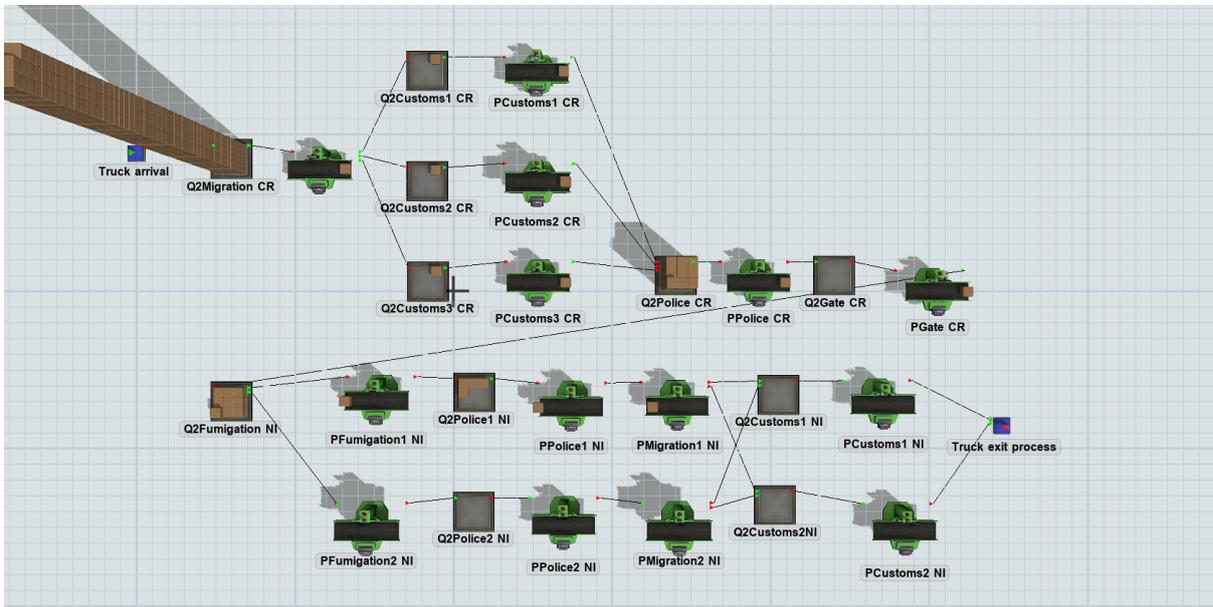


Appendices B | Simulation visuals

Day 6

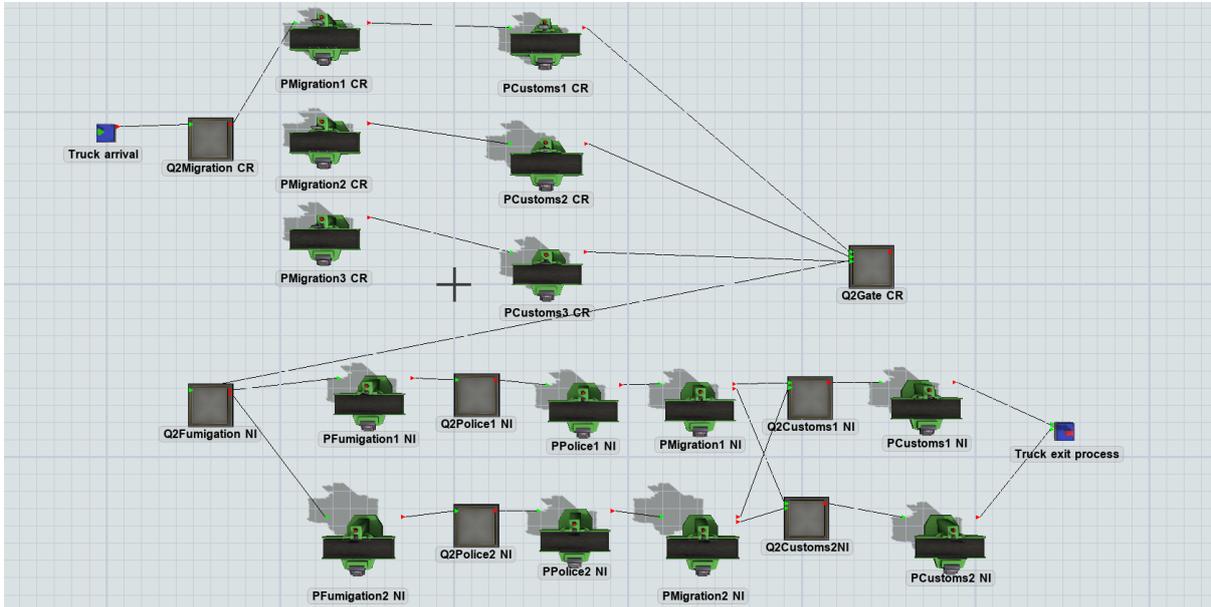


Day 7

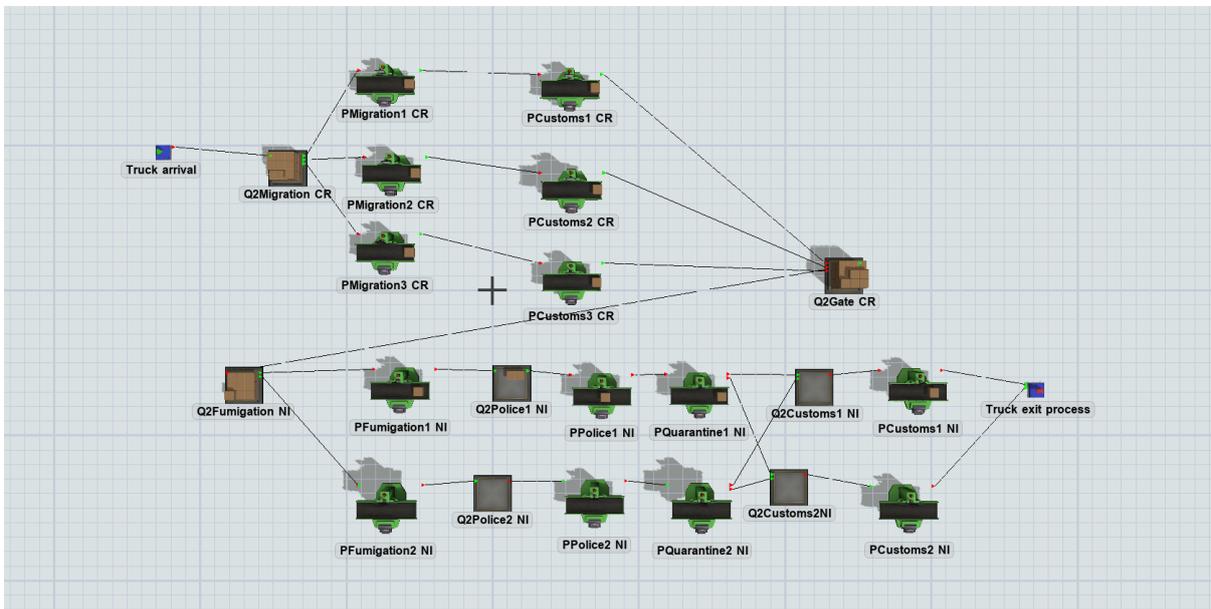


Simulation II

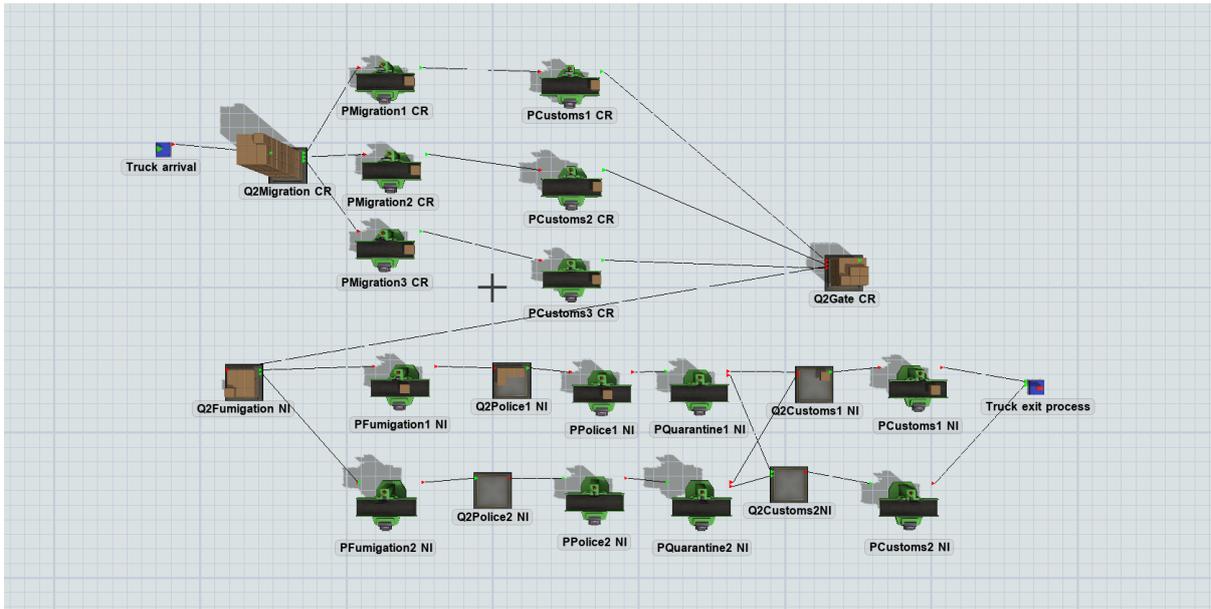
Servers and queues distribution



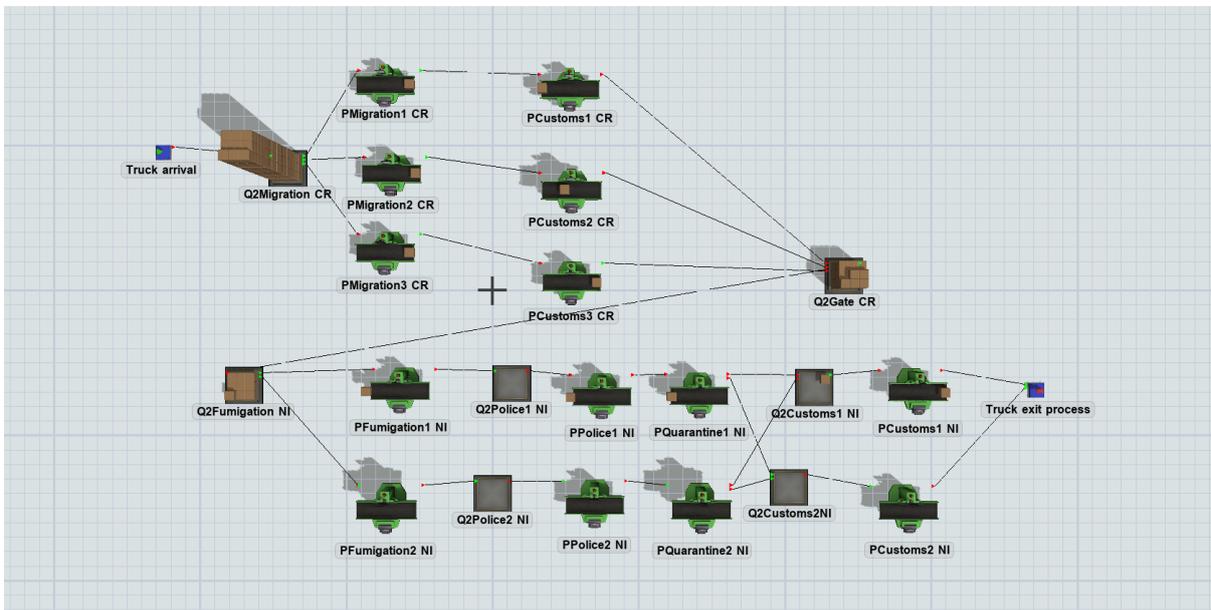
Day 1



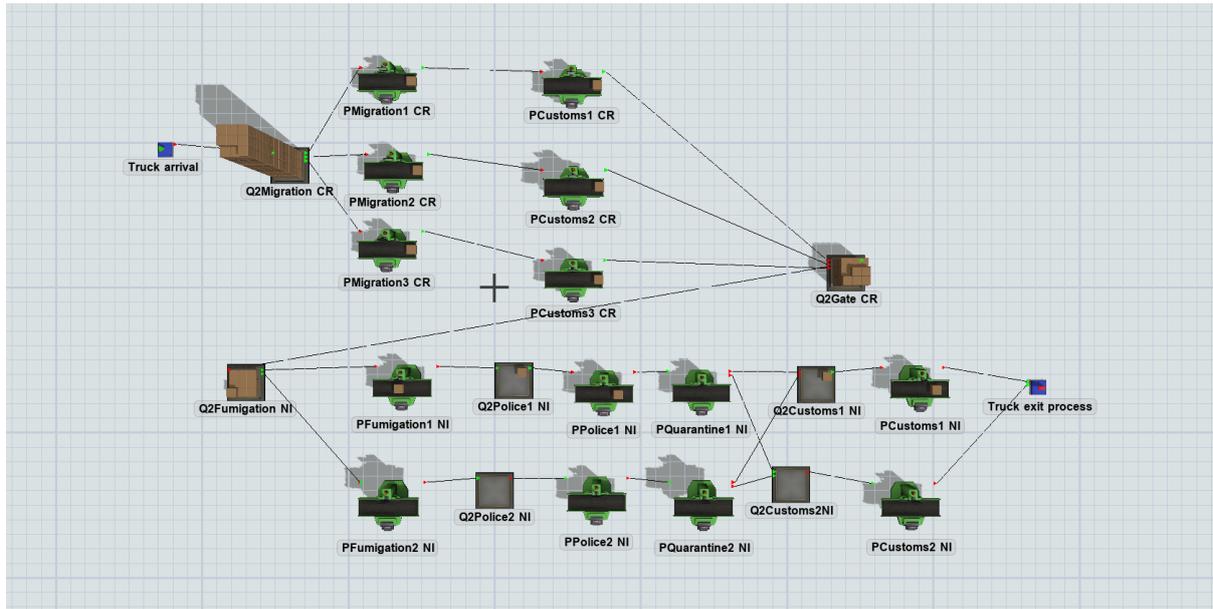
Day 2



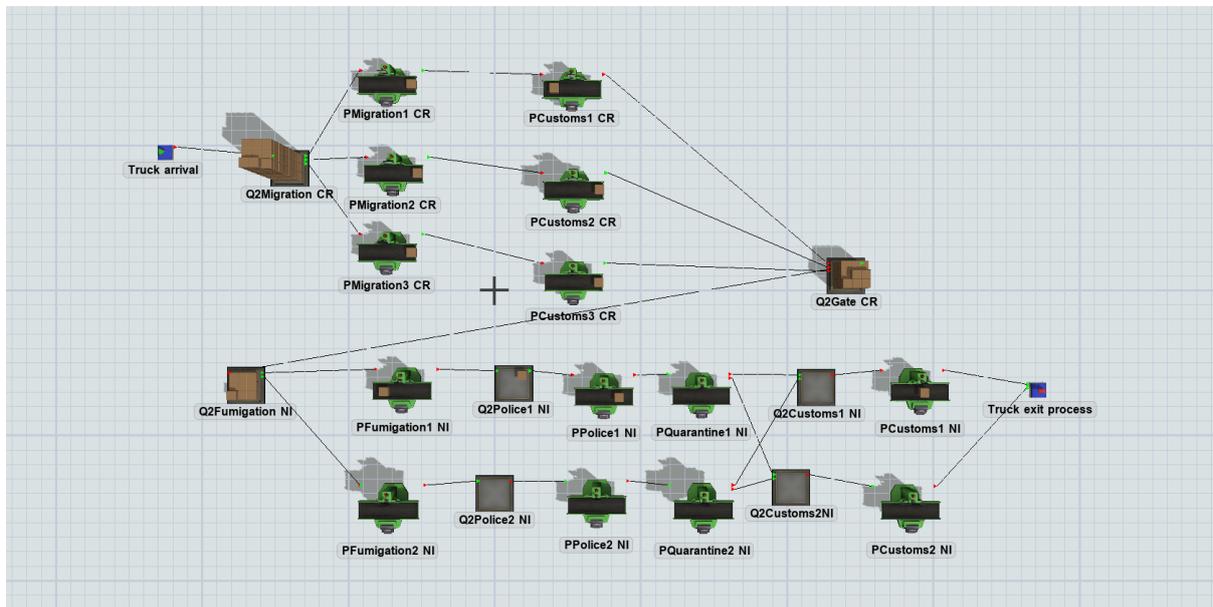
Day 3



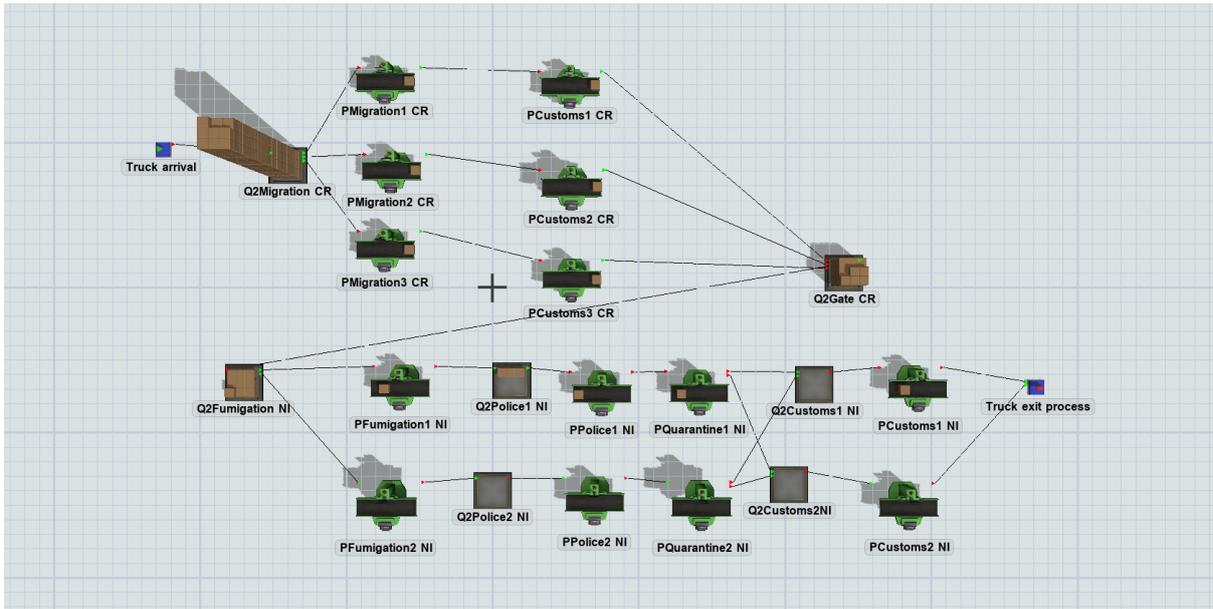
Day 4



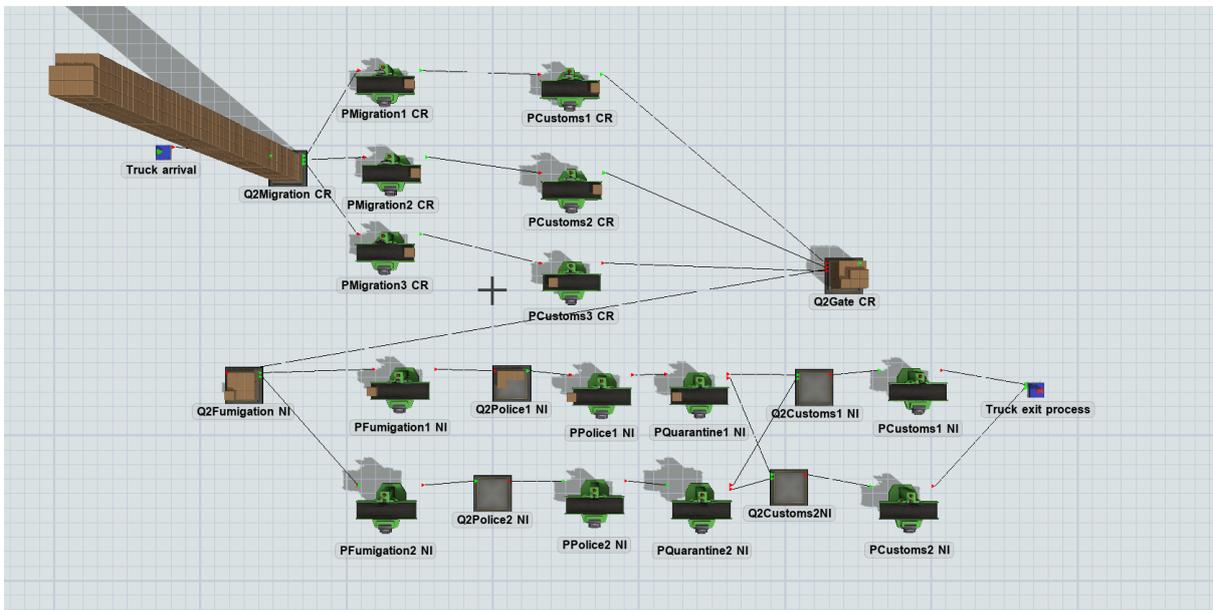
Day 5



Day 6

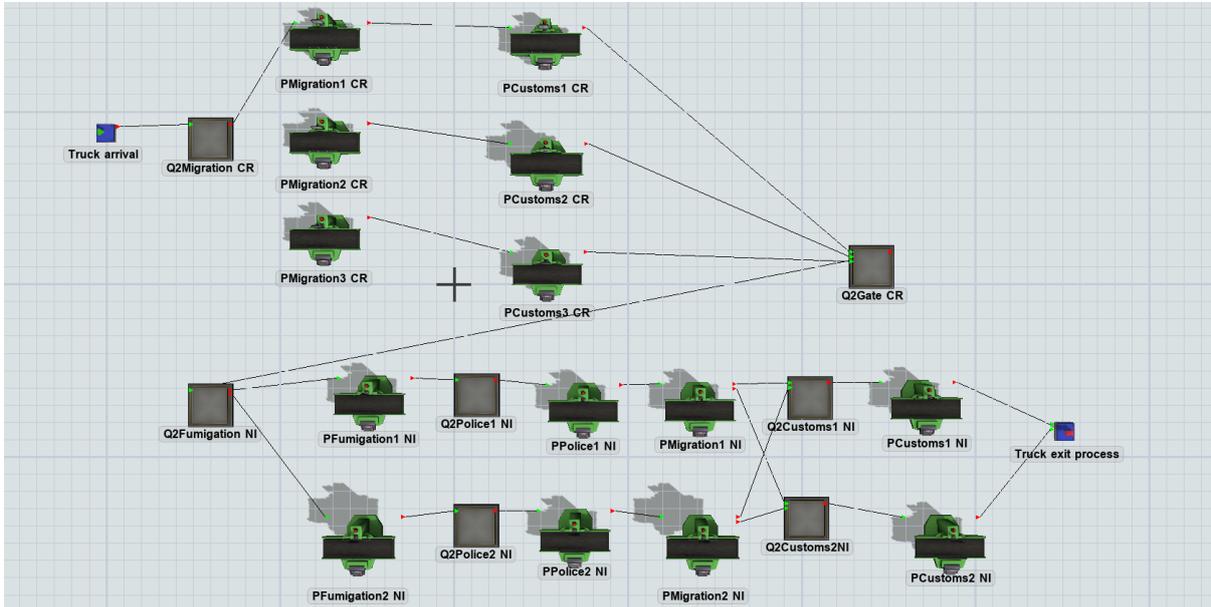


Day 7

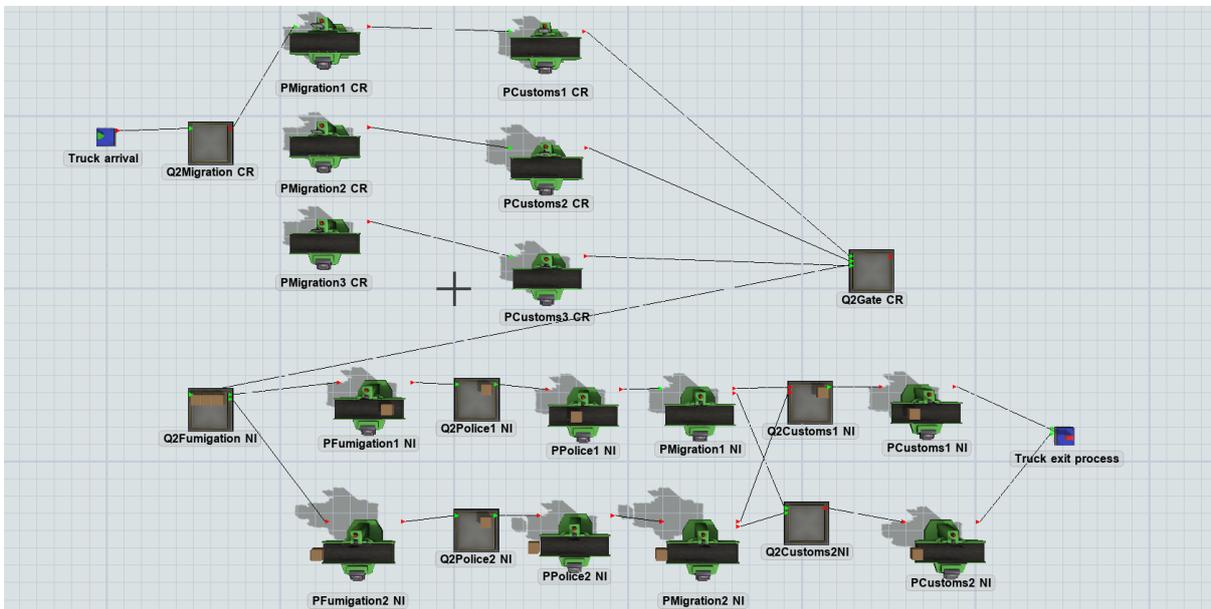


Simulation III

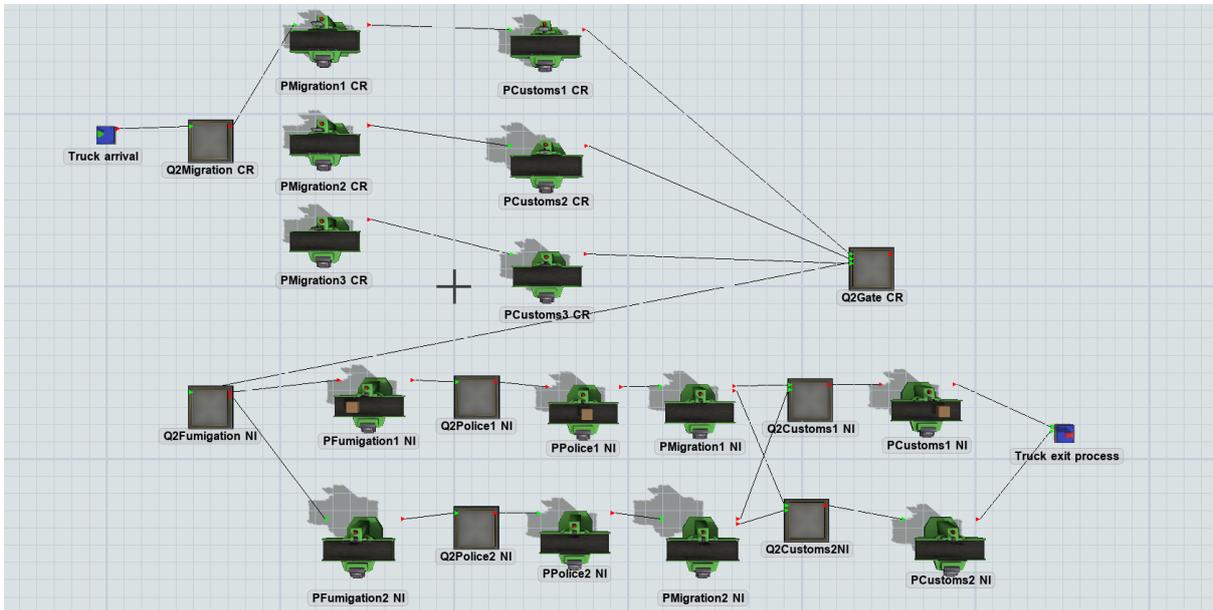
Servers and queues distribution



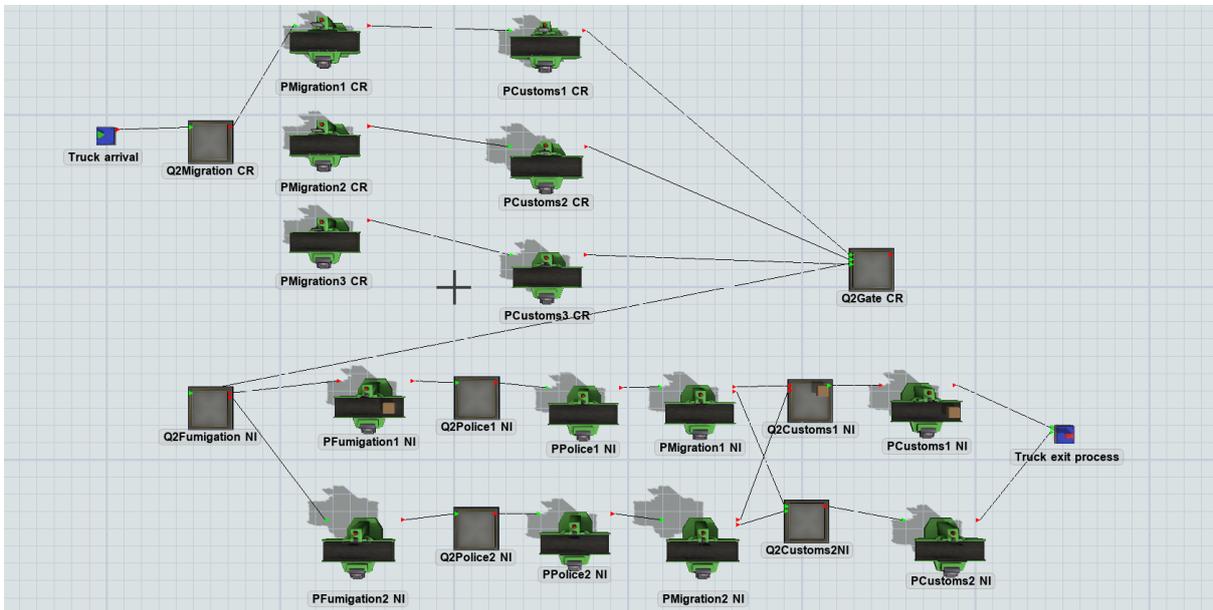
Day 1



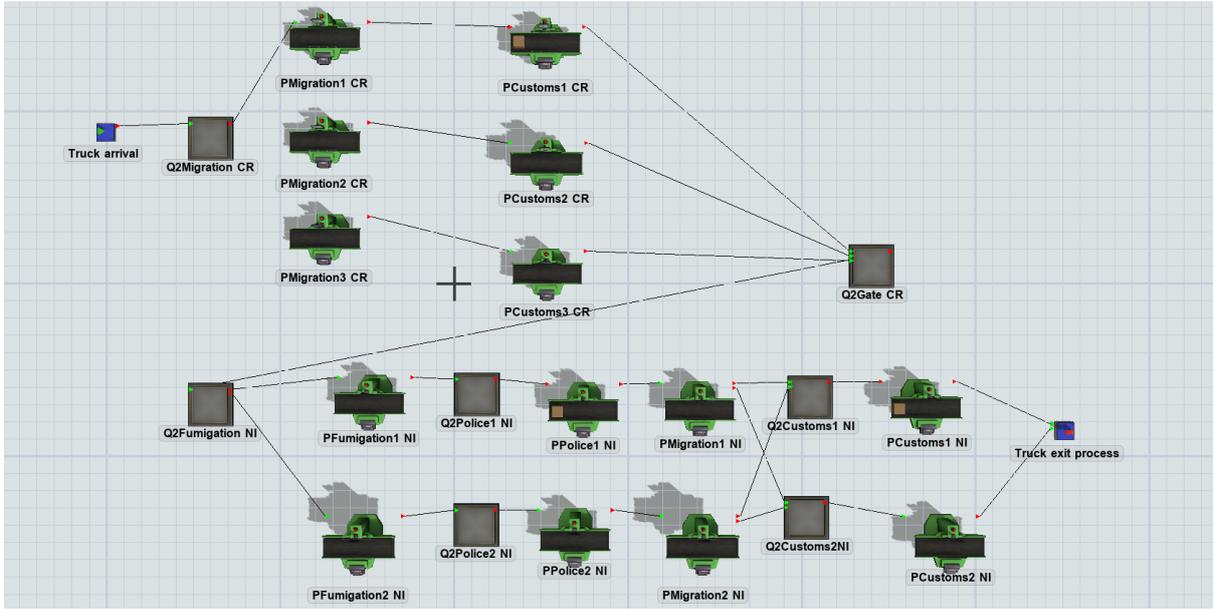
Day 2



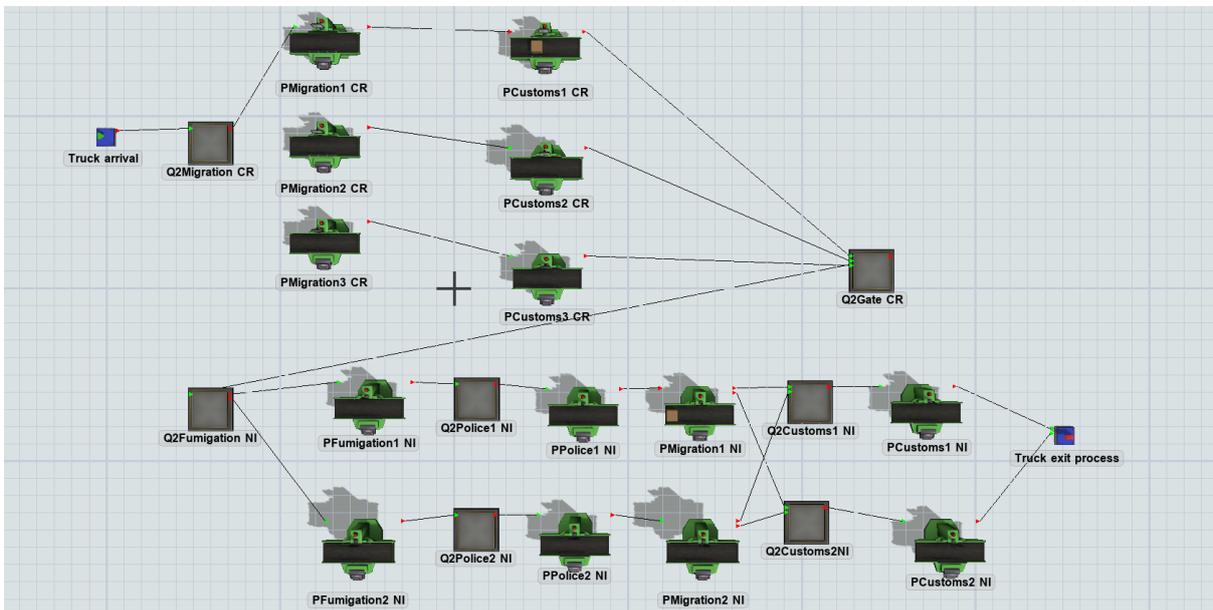
Day 3



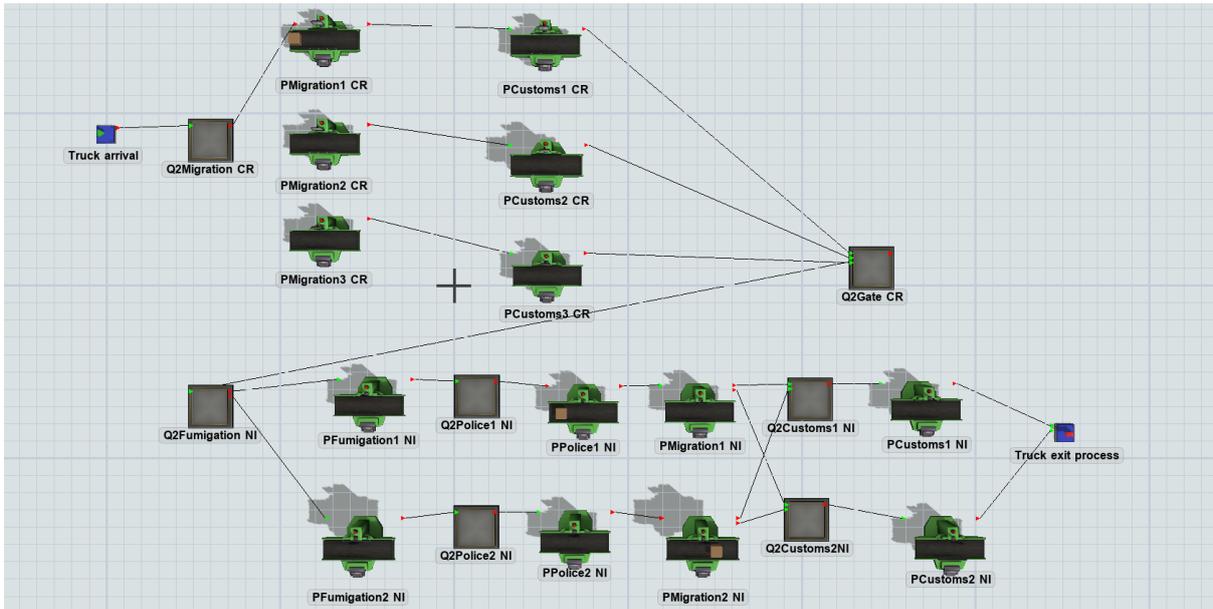
Day 4



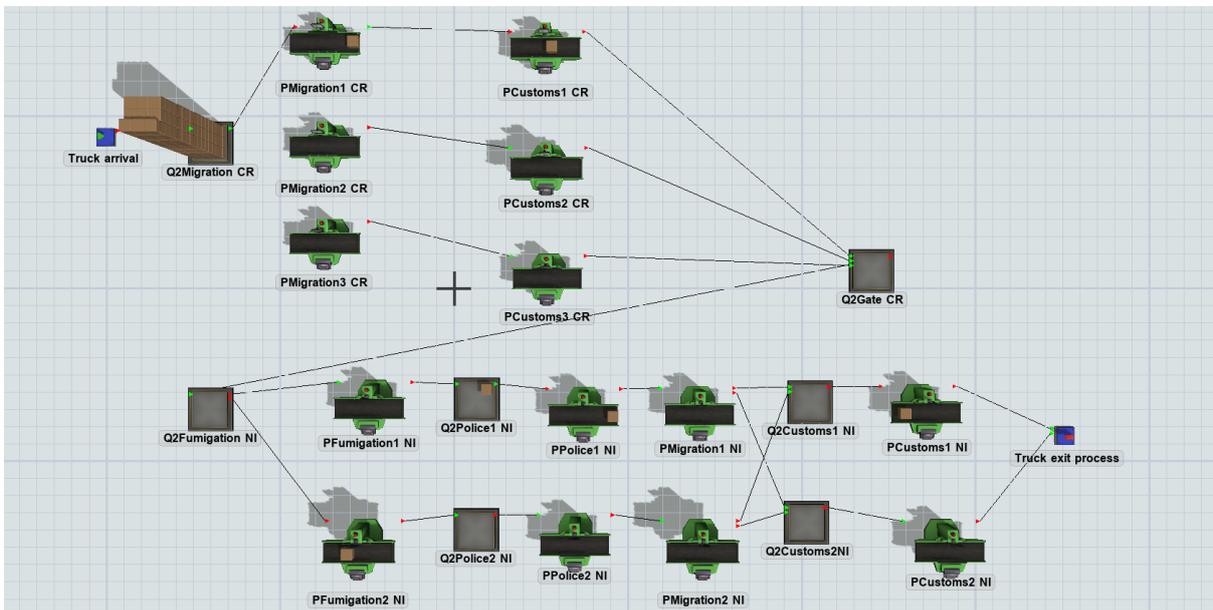
Day 5



Day 6



Day 7



Appendices C | Simulation Results

Simulation I

This simulation represents the current situation of the Peñas Blancas land border post. All servers are set to work from 6:00 AM until midnight from Monday to Sunday, except for two Costa Rican customs booth/servers: one opens from 8:00 AM until 20:00 PM and the other one from 10:00 AM to 16:00 PM. Chapter 5 explain the capacity of each queue, the statistical distribution of the processes, and the inter-arrival time.

FIGURE 11.1 presents the accumulated number of trucks inputted into the process, the number of trucks that finished the Costa Rican and Nicaraguan process (outputs or throughputs) and the difference between the input and output of trucks per day. The number of trucks pending to be finished keeps increasing per day if the number of servers in Nicaragua remains as presented in TABLE 5.8 where fumigation, police, and migration have one server each.

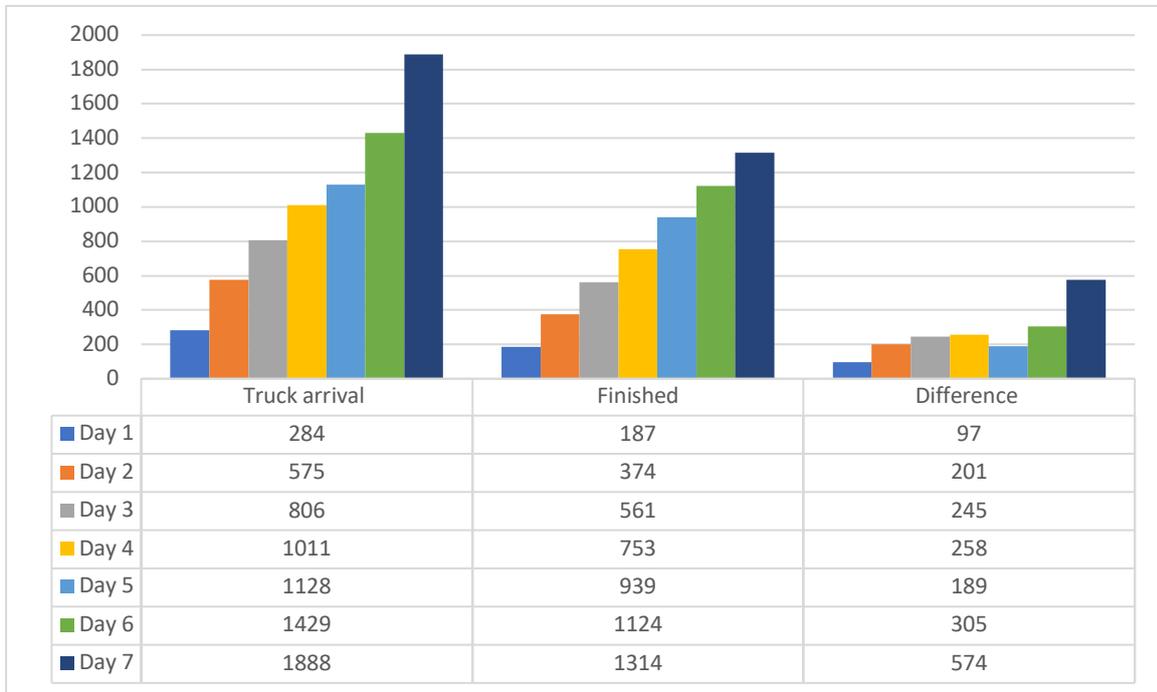
Based on the performed interview to the Peñas Blancas border coordinator, mostly on Thursdays, the Costa Rican customs authorities seek help from the Nicaraguan authorities to open an extra server for each of the following processes: fumigation, police, and migration. These extra servers are opened for certain hours when needed and when agreed between the customs authorities of Costa Rica and Nicaragua.

The double servers are usually only opened from 12:00 midday to 00:00 midnight on Thursday. They are not open all the time because these extra servers are used for the export process of Nicaragua.

FIGURE 11.2 shows the accumulated input and output of trucks per day with double servers for fumigation, police, and migration processes in Nicaragua from 12:00 midday to 00:00 midnight on Thursday.

FIGURE 11.1.

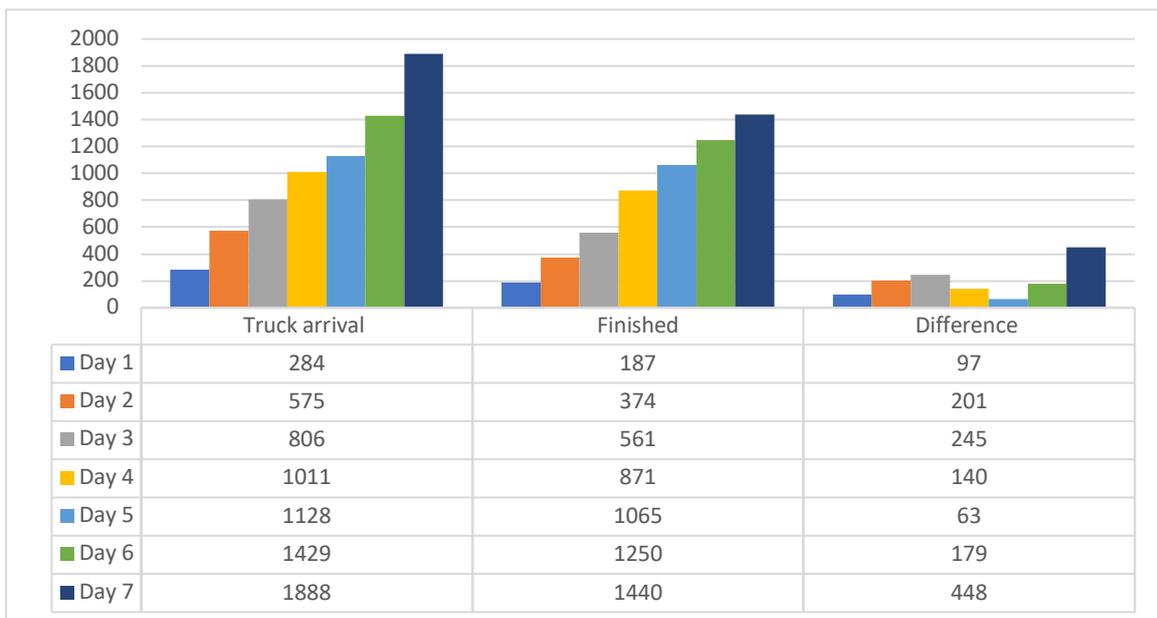
Accumulated number of trucks arriving and finishing the process per day with single server for fumigation, police, and migration processes in Nicaragua, current situation



Source. Own Elaboration based on the simulation results.

FIGURE 11.2.

Accumulated number of trucks arriving and finishing the process per day with double server for fumigation, police, and migration processes in Nicaragua



Source. Own Elaboration based on the simulation results.

When a second sever of fumigation, police and migration in Nicaragua is open for 12 hours on Thursday, the number of outputs increases significantly. On day 7 instead of having 565 trucks waiting in the queues to be processed, the number dropped to 385 trucks.

Opening an additional set of booths to perform the fumigation, police and migration procedures at Nicaragua on Thursday for a limited period of time is conditioned to the acceptance of the Nicaraguan customs officers. The time in which the additional booths are open can vary significantly and, in some weeks, there is no additional lane at all. Due to this uncertainty, Simulation I do not consider this possibility.

FIGURE 11.3 shows the throughputs per day in each process or inspection and queues. Day 1 has the highest number of throughputs in Costa Rica because is the day in which all the servers and queues are empty, this means that there are no blockages in the subsequent step.

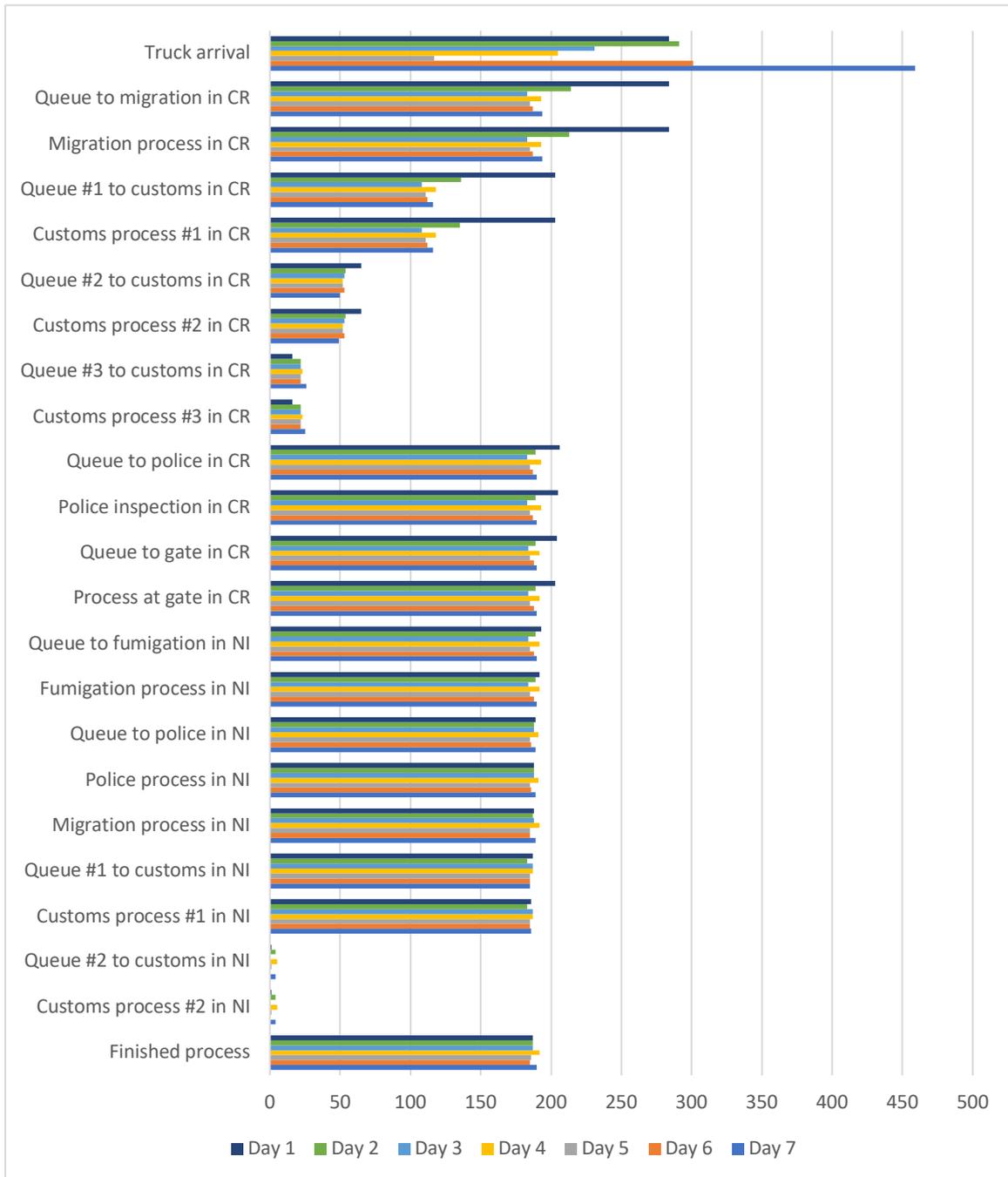
When looking at the number of throughputs in the order of the events, it is possible to see that 284 trucks arrived on Day 1, all the trucks were processed for customs in CR by using the three available booths. Costa Rican Custom booth #1 is the most utilized booth. Costa Rican Custom booth #2 and #3 are not utilized frequently as the subsequent processes are blocked. The next event is the queue to the CR police and its inspection and then the queue to gate and process gate in CR. As of the “queue to police in CR”, the number of throughputs reduces to 206, 205, 204 and 203 respectively. In other words, there were 78 trucks accumulated in Day 1 at the “queue to police in CR” (which has the maximum capacity of 100 trucks) and 1 truck in the “queue to gate in CR” (which has the maximum capacity of 1 truck). The next events are from Nicaragua, which has a lower throughput rate. The “queue to fumigation in NI” (first NI queue) has a throughput of 193 trucks and at the end of Day 1, a total of 197 trucks finished the whole impot cycle in Nicaragua.

As of the beginning of the operating time of Day 3, the “queue to police in CR” has already reach its capacity. Therefore, as of Day 3, the number of trucks that can be processed in all the Costa Rican servers are constraint to the Nicaraguan servers’ capacity. In other words, the trucks arrive to the CR side, but, the number of trucks that the Costa Rican migration (first server in CR) can processes is constraint to the throughput capacity of NI.

The above explanation does not apply to Day 2 because there is still some capacity in the “queue to police in CR”, therefore, the number of throughputs in the Costa Rican Process is higher and not dependant to the Nicaraguan servers’ capacity.

The number of throughputs in the Nicaraguan process remains fairly the same. The customs process booth # 2 in Nicaragua is basically unused because the previous Nicaraguan servers are not able to process enough trucks, therefore, customs process booth # 2 in Nicaragua is mostly “idle”.

FIGURE 11.3.
Throughput per day, per queue and server



Source. Own Elaboration based on the simulation results.

The Costa Rican customs process #2 and 3 were also blocked (26% and 13% respectively), but they were mostly in “idle” as explained previously. There is some percentage of blockage in the Nicaraguan servers because the land border post closes at midnight, therefore, the trucks are not able to move on to the next stage and they stay overnight waiting for the offices to open again at 6:00, the next day.

. The Costa Rican customs process #2 and 3 were also blocked (26% and 13% respectively), but they were mostly in “idle” as explained previously. There is some percentage of blockage in the Nicaraguan servers because the land border post closes at midnight, therefore, the trucks are not able to move on to the next stage and they stay overnight waiting for the offices to open again at 6:00, the next day.

FIGURE 11.4 shows the average state per server and queue. There are five states, two applicable to queues (empty and releasing) and three to processes (idle, processing and blocked). “Empty” means that there are no contents/trucks waiting in the queue and “releasing” occurs when trucks arrive to the queue and sent to a server. Regarding the states of the servers, “idle” means that they are waiting for a content/truck to arrive, in other words, in this state, the servers are not working. “Processing” occurs when the server is performing the assigned process. “Blocked” means that the server has finished performing the task or process (in other words the “processing” state has finished), but the content/truck cannot move forward because the next step (which can be a queue or another server) cannot receive the truck as it is full or occupied at that time.

From these data, several remarks can be made. First, there are queues that are mostly empty. The two emptiest queues are in Nicaragua. The “queue #2 to customs in NI” is practically unused, while the “queue #1 to customs in NI” is 85% of the time empty. These queues are usually empty because the trucks move directly from the migration process to the customs process booths.

Second, there are servers that are underutilized. The server named “customs process #2 in NI”, is its mostly in an “idle” mode. During the 7-day simulation, only 15 trucks were processed in such booth. The servers named “customs process #2 in CR” and “customs process #3 in CR”, are mostly in an “idle” mode as they only function during certain hours of the day. Furthermore, Day 1 was the day in which both booths had a higher percentage of “idle” time when compared to the other days. This occurs because there was not blockage in the next

steps and one single customs process booth (the #1) was able to carry out most of the trucks/content “processing” activity.

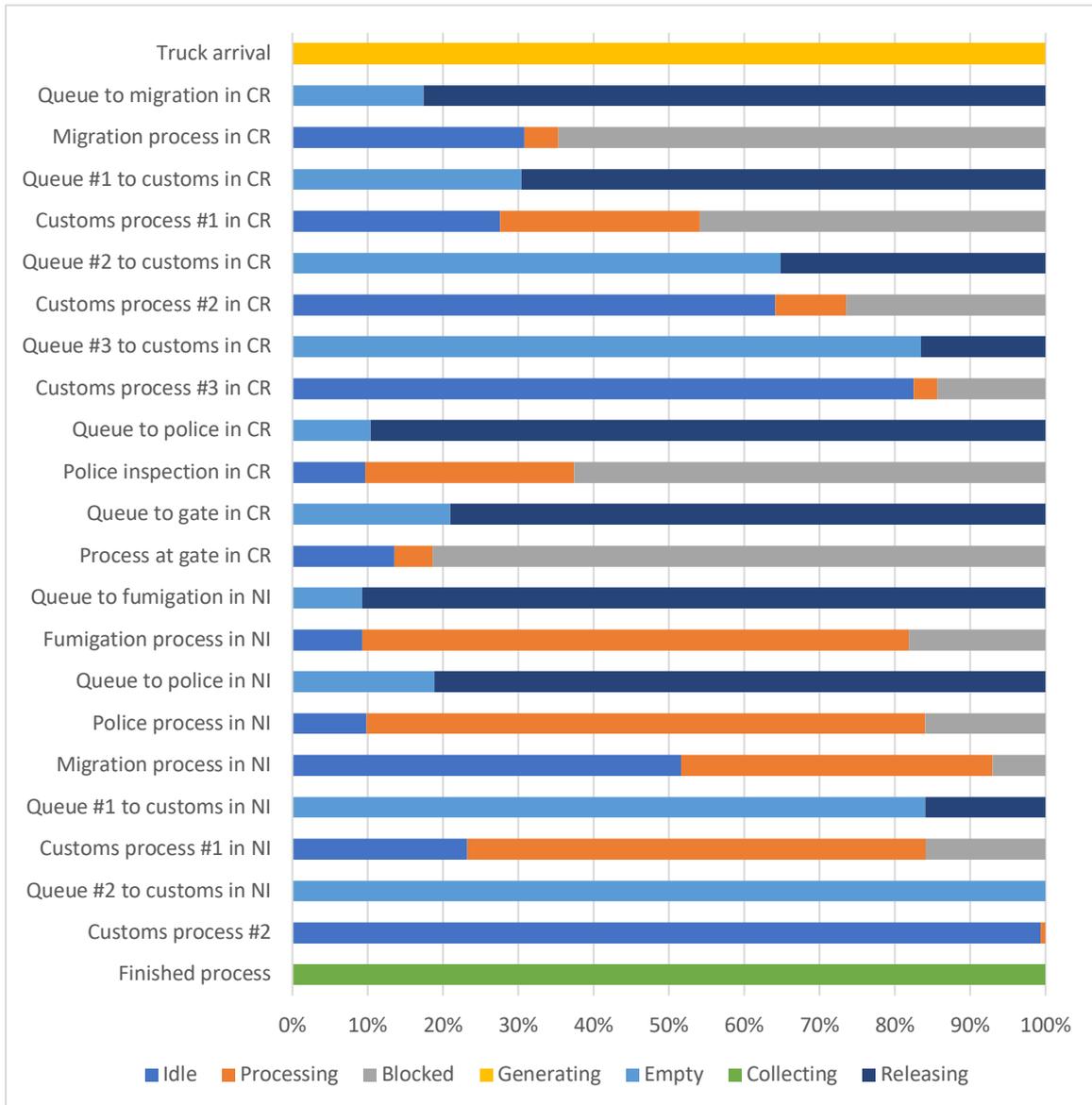
Third, the servers with the highest “processing” rate are in Nicaragua. The order of servers with the highest processing rate are: Nicaraguan police (75%), Nicaraguan fumigation (73%), Nicaraguan custom process #1 (61%) and Nicaraguan migration process (41%).

Fourth, the servers with the highest “blocking” rate are in the Costa Rica side. The order of servers with the highest blocking rate are: process at the Costa Rican gate (82%), Costa Rican migration process (65%), Costa Rican police inspection (63%), and Costa Rican customs process #1 (46%). The Costa Rican customs process #2 and 3 were also blocked (26% and 13% respectively), but they were mostly in “idle” as explained previously. There is some percentage of blockage in the Nicaraguan servers because the land border post closes at midnight, therefore, the trucks are not able to move on to the next stage and they stay overnight waiting for the offices to open again at 6:00, the next day.

FIGURE 11.4.

Average state per queue and server

Appendices C | Simulation Results



Source. Own Elaboration based on the simulation results.

TABLE 11.1 shows the maximum capacity of trucks that can be absorbed per queue and the number of trucks located in each one of them at midnight per day. These trucks remain parked in the queues until the next day 6:00 am when the border post’s work resumes. The first queue called “queue to migration in CR” can basically absorb an unlimited number of trucks because they lined up in the Interamerican highway. This is mainly the queue that the Border Integration Program aims to reduce.

All other queues have a maximum fixed capacity. Most of the time, such queues are all full by the time the border post closes. Queue #2 and #3 to customs in CR have no trucks waiting because the operating hours of the second and third customs booths are limited.

It takes less than two days to have the “queue to police in CR” at the maximum capacity. That is why as of Day 2, such queue remains always full. The “queue to fumigation in NI” is always at its maximum capacity too. The next queue in Nicaragua is “queue to police in NI” and such queue is not always full, which suggest that an important bottleneck is the fumigation process in NI. The queues to the customs process in Nicaragua are mostly empty because as soon as the trucks finishes the police and migration procedure, they immediately start the Nicaraguan customs process.

TABLE 11.1.
Number of trucks in queues at midnight, per day

Object	MAX	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Queue to migration in CR	N/A	0	77	125	137	69	183	450
Queue #1 to customs in CR	1	0	1	1	1	1	1	1
Queue #2 to customs in CR	1	0	0	0	0	0	0	0
Queue #3 to customs in CR	1	0	0	0	0	0	0	0
Queue to police in CR	100	78	100	100	100	100	100	100
Queue to gate in CR	1	1	1	0	1	1	0	0
Queue to fumigation in NI	10	10	10	10	10	10	10	10
Queue to police in NI	4	3	4	0	1	1	3	4
Queue #1 to customs in NI	1	0	0	1	1	0	0	0
Queue #2 to customs in NI	1	0	0	0	0	0	0	0
TOTAL QUEUE PER DAY		92	193	237	251	182	297	565

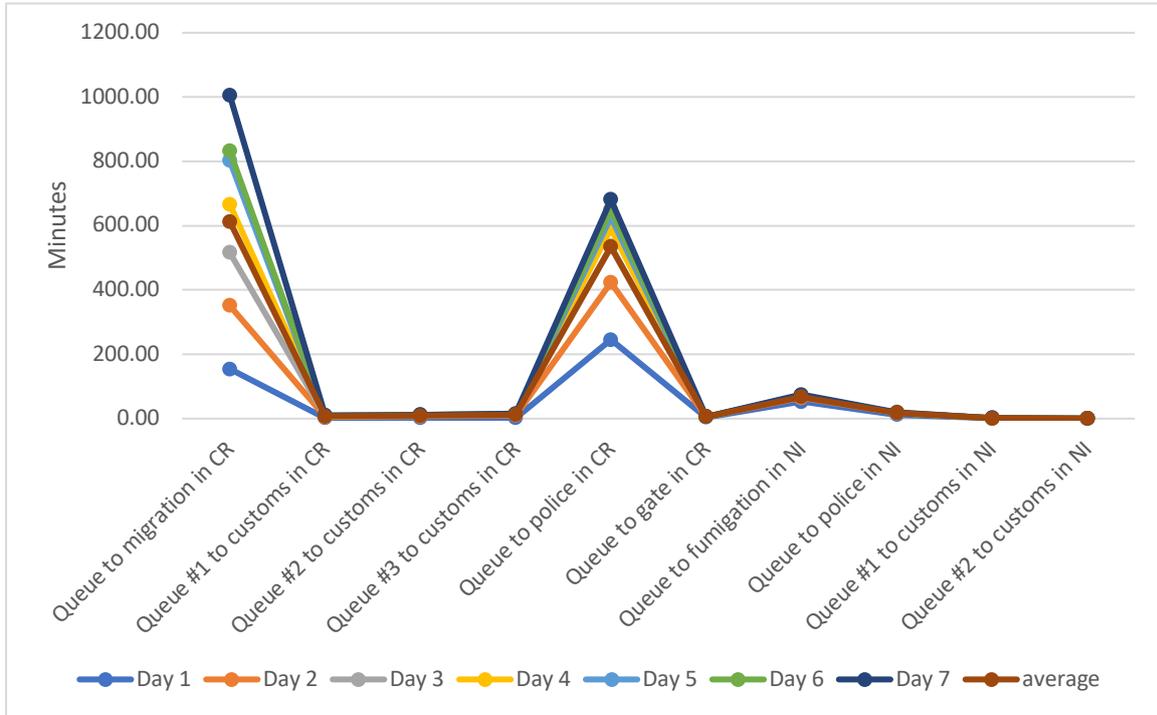
Source. Own Elaboration based on the simulation results.

FIGURE 11.5, FIGURE 11.6 and TABLE 11.2 present the average stay time of the truck per queue and server. Stay time is calculated from the moment it enters the queue or server until the moment it exits. Stay time is different from the processing time. The duration of the processing might be shorter than that stay time because once the process has ended the next step might be full or occupied and therefore it prevents the truck to move forward.

In terms of queues, “queue to migration in CR” (10 hours in average), “queue to police in CR” (8.9 hours in average) and “queue to fumigation in NI” (67.8 minutes in average) have the highest stay time because they have the highest number of trucks that can be absorbed in the queue and therefore, the stay time is longer.

FIGURE 11.5.

Stay time of trucks per queue per day, in minutes



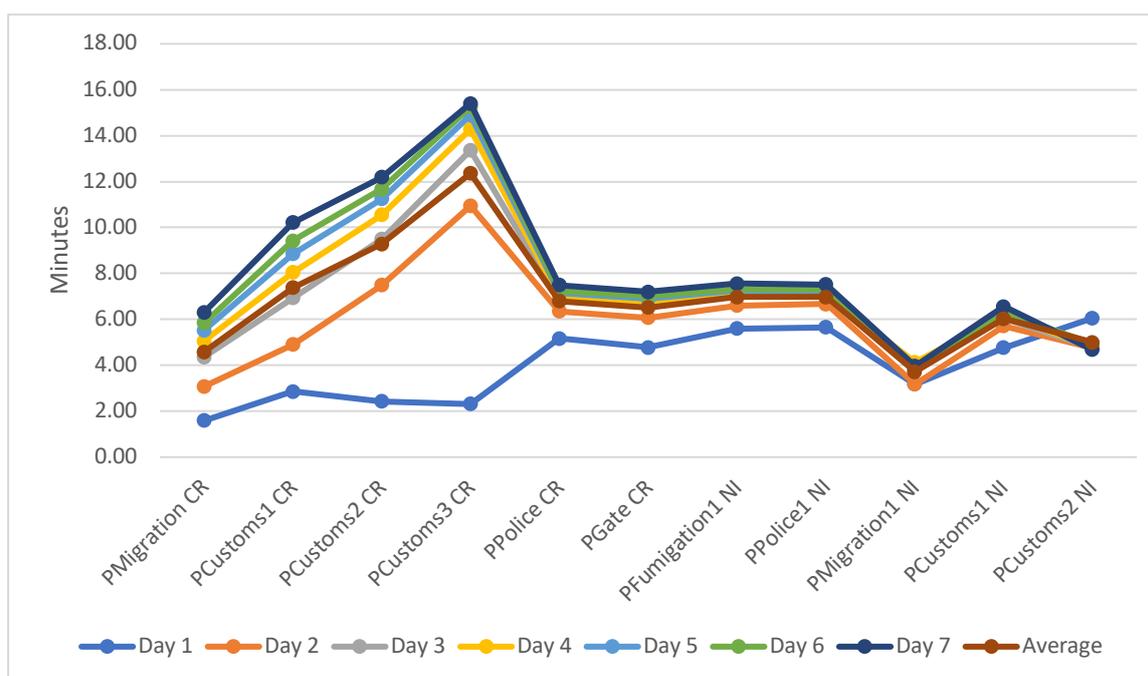
Source. Own Elaboration based on the simulation results.

In terms of processes/servers, the two longest stay time are in Costa Rica, which are the Costa Rican customs process with an average stay time of 7.38, 9.28 and 12.36 minutes on booth 1, 2 and 3 respectively. These are also the servers that have the highest blockage rate (See).

FIGURE 11.6.

Stay time of trucks per server per day, in minutes

Appendices C | Simulation Results



Source. Own Elaboration based on the simulation results.

TABLE 11.2.

Stay time of trucks per process and queue per day, in minutes

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Average
Queue to migration in CR	153.78	351.84	516.74	666.42	802.18	832.21	1005.18	612.73
Migration process in CR	1.59	3.08	4.36	5.05	5.53	5.85	6.31	4.58
Queue #1 to customs in CR	2.33	4.56	6.67	7.83	8.67	9.26	10.07	7.11
Customs process #1 in CR	2.86	4.90	6.93	8.04	8.85	9.42	10.21	7.38
Queue #2 to customs in CR	2.30	7.34	9.31	10.36	11.03	11.45	11.94	9.09
Customs process #2 in CR	2.43	7.49	9.49	10.56	11.24	11.67	12.19	9.28
Queue #3 to customs in CR	1.85	10.40	12.64	13.51	14.13	14.58	14.64	11.68
Customs process #3 in CR	2.31	10.95	13.36	14.28	14.90	15.26	15.41	12.36
Queue to police in CR	245.53	423.07	535.82	591.21	627.04	649.75	680.85	534.55
Police inspection in CR	5.17	6.35	6.82	6.99	7.14	7.23	7.49	6.79
Queue to gate in CR	4.46	5.76	6.31	5.97	6.17	6.35	6.33	5.95
Process at gate in CR	4.77	6.07	6.61	6.76	6.89	7.01	7.20	6.52
Queue to fumigation in NI	52.63	64.20	68.85	70.18	71.68	72.49	74.85	67.96
Fumigation process in NI	5.60	6.60	7.00	7.12	7.25	7.32	7.57	6.97

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Average
Queue to police in NI	11.99	17.05	19.75	18.25	18.21	17.58	18.49	17.52
Police process in NI	5.66	6.67	6.99	7.09	7.22	7.30	7.52	6.97
Migration process in NI	3.18	3.18	3.81	4.13	3.94	3.82	3.96	3.72
Queue #1 to customs in NI	0.96	0.91	0.85	1.33	1.59	1.46	1.60	1.29
Customs process #1 in NI	4.77	5.72	6.03	6.17	6.25	6.33	6.56	6.03
Queue #2 to customs in NI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Customs process #2 in NI	6.05	4.77	4.77	4.81	4.92	4.92	4.67	5.00

Source. Own Elaboration based on the simulation results.

Simulation II

Simulation II represents the Peñas Blancas land border post with the new Costa Rican infrastructure blueprint.

For the configuration of this simulation, the inter arrival time of trucks per day did not vary between the three simulations. Furthermore, the processing time of each server remained the same for both Costa Rica and Nicaragua. Some servers and queues in the Costa Rican side were removed as per the new blueprint. The number of trucks that can be lodged in each Costa Rican queue was updated (see chapter 5 for the exact data details inputted in this simulation).

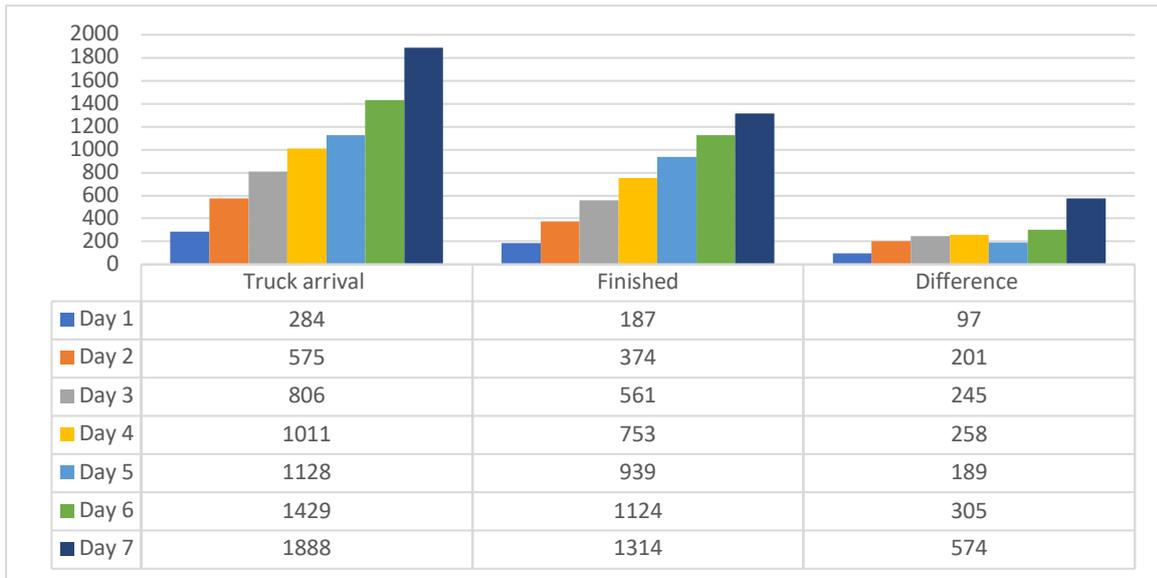
FIGURE 11.7 presents the accumulated number of trucks inputted into the process and the difference between the input and output of trucks.

When comparing FIGURE 11.1 and FIGURE 11.7 there is no change whatsoever. Because the interarrival time of trucks was not modified, the number of trucks arriving to the Peñas Blancas land border post did not vary in the Simulation II. The number of trucks that have finished the whole cycle did not vary either, even though on the Costa Rican side the number of queues and processes were reduced. This shows that changes in the Costa Rican Peñas Blancas infrastructure will not impact on the total throughput of trucks in Nicaragua.

FIGURE 11.7.

Number of trucks arriving and finishing the process per day with single server for fumigation, police, and migration processes in Nicaragua, new Peñas Blancas blueprint

Appendices C | Simulation Results



Source. Own Elaboration based on the simulation results.

FIGURE 11.8 presents the total throughput per day and per step of the whole import and export cycle. When looking at the number of throughputs in the order of the events, Simulation I and II coincides that Day 1 has a higher throughput rate because all the queues and server were empty when the simulation started to run.

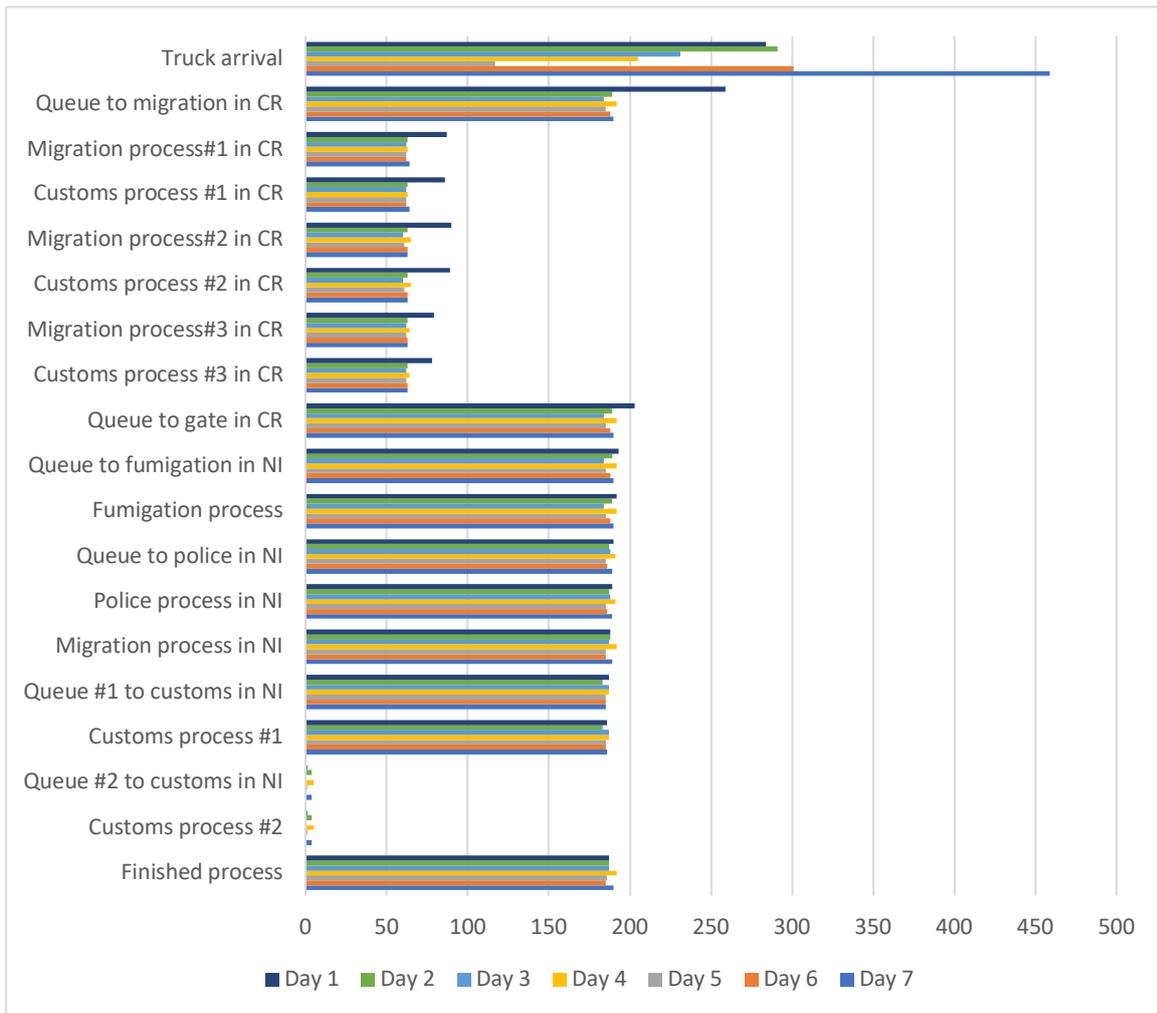
In simulation II, there are three export booths, inside each booth, there is one migration officer and one customs officer. The processing time of both officers remained the same as in Simulation I.

On Day 1, 284 trucks arrived at the land border post, they were processed by the migration and customs officers in CR by using the three available booths. These three booths were fairly equally utilized. The next event is the queue to gate (the queue to CR police and its inspection and gate process are eliminated in the new infrastructure). On the “queue to gate in CR”, the number of throughputs reduces to 203 and from that point onwards in Nicaragua, the throughput reduces to 192 and remains relatively constant until 187 trucks finish the Nicaraguan import process.

On Day 1, the “queue to gate in CR” has already reach its capacity. Therefore, as of Day 2, the number of trucks that can be processed in all the Costa Rican server are constrained to the Nicaraguan servers’ capacity. In other words, the trucks arrive to the CR side, but the number of trucks that the Costa Rican migration (first server in CR) can processes is constrained to the throughput capacity of NI.

The number of throughputs in the Nicaraguan process remains fairly the same. The customs process booth # 2 in Nicaragua is basically unused because the previous Nicaraguan servers are not able to process enough trucks, therefore, customs process booth # 2 in Nicaragua is mostly “idle”.

FIGURE 11.8.
Throughput per day, per queue and server

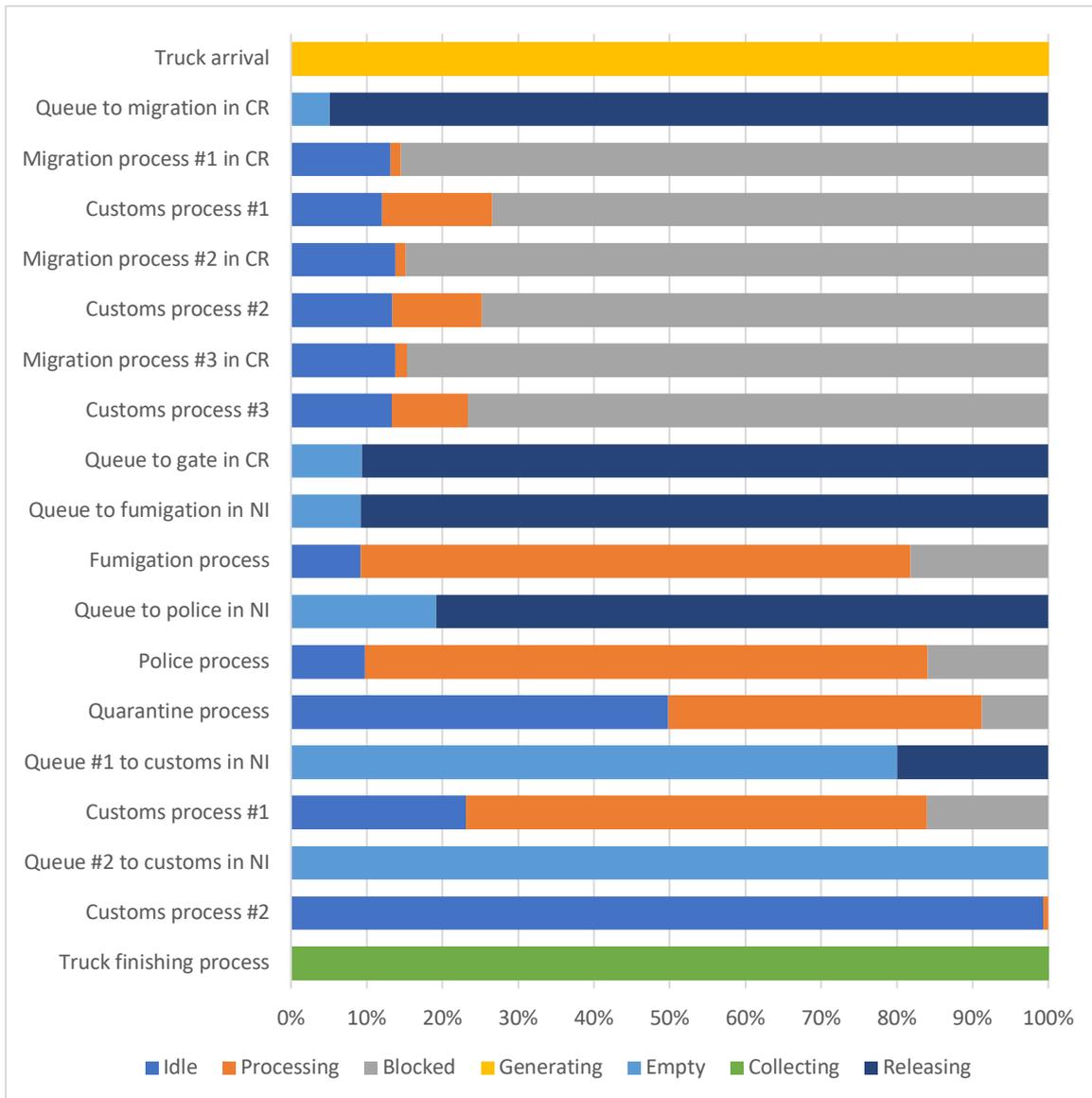


Source. *Own Elaboration based on the simulation results.*

FIGURE 11.9 shows the average state per server and queue. In this case, the states of all the Nicaraguan queues and servers remain the same when compared to Simulation I. As per the Costa Rican servers, there is a significant change, all six servers are practically blocked most of the time. The three migration servers are blocked around 86% of the time, while the

customs servers are blocked between 77% and 74% of the time. All six Costa Rican servers are “idle” 13% of the time approximately and the “processing” time varies from 1% (for migration) to 15% (for customs).

FIGURE 11.9.
Average state per queue and server



Source. *Own Elaboration based on the simulation results.*

With the new infrastructure blueprint, there are only two queues in the Costa Rican side. The first one is the queue to migration in Costa Rica in which 100% of the time they are “releasing” trucks. With regards to the queue to gate in Costa Rica, almost 92% of the time is “releasing”

trucks. This is an increase in comparison to the replication model (Simulation I) where 80% of the time of such queue is in a “releasing” state.

TABLE 11.3 shows the maximum number of trucks that can be absorbed per queue and the number of trucks located in each queue at midnight per day. The total number of trucks queuing per day has a very little variation between simulation I and II. The most important difference is that on simulation II, the longest queue is the “queue to migration in CR”. On day 7, Simulation I had 450 trucks in such queue while in Simulation II a total of 501 trucks are waiting. This is an increase of approximately 12% of the queue.

Additionally, a noticeable difference between Simulation I and II is that the queue right after the “Costa Rican customs process” is maxed out on Day 1 for Simulation II versus Day 2 in Simulation I. This happens because the capacity of the queues is different in Simulation I and II, the first one has a 100 trucks capacity while the second one 50 trucks.

TABLE 11.3.
Number of trucks in queues at midnight, per day

Object	MAX	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Queue to migration in CR	N/A	25	127	174	187	119	232	501
Queue to gate in CR	50	50	50	50	50	50	50	50
Queue to fumigation in NI	10	10	10	10	10	10	10	10
Queue #1 to police in NI	4	2	4	0	1	1	3	4
Queue #1 to customs in NI	1	0	1	1	1	0	0	0
Queue #2 to customs in NI	1	0	0	0	0	0	0	0
TOTAL QUEUE PER DAY		87	192	235	249	180	295	565

Source. Own Elaboration based on the simulation results.

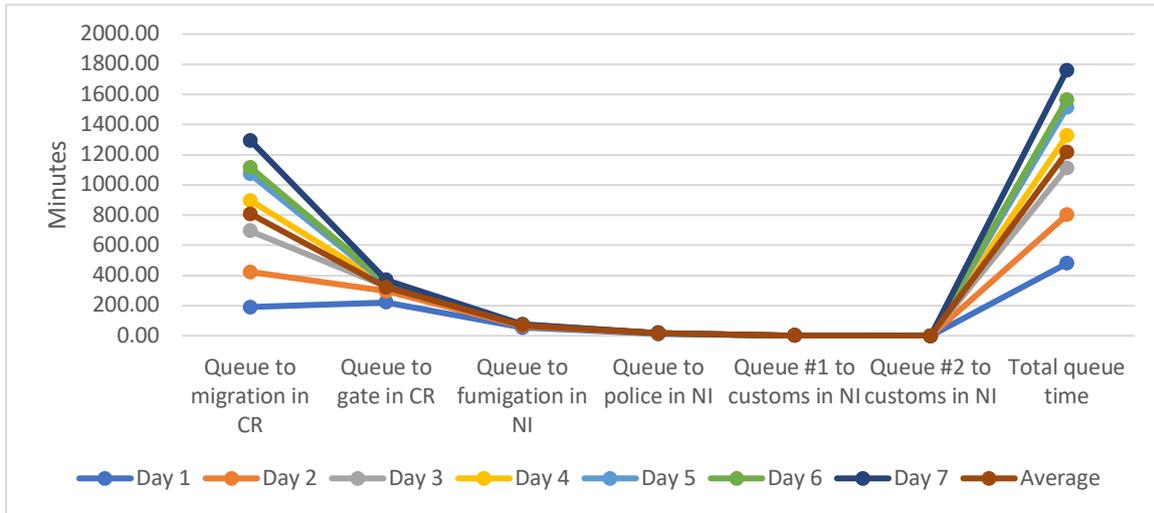
TABLE 11.4 present the average stay time per queue and server. In terms of queues, the total average stay time in queues is 20.3 hours. The longest queue is “queue to migration in CR” (13.5 hours) followed by “queue to gate in CR” (5.3 hours). In terms of servers, Costa Rica has the longest stay time with 36.18, 35.41 and 36.98 minutes on export booth 1, 2 and 3

respectively. Each export booth has a migration and customs officers. These are also the servers that have the highest blockage rate (See

FIGURE 11.9).

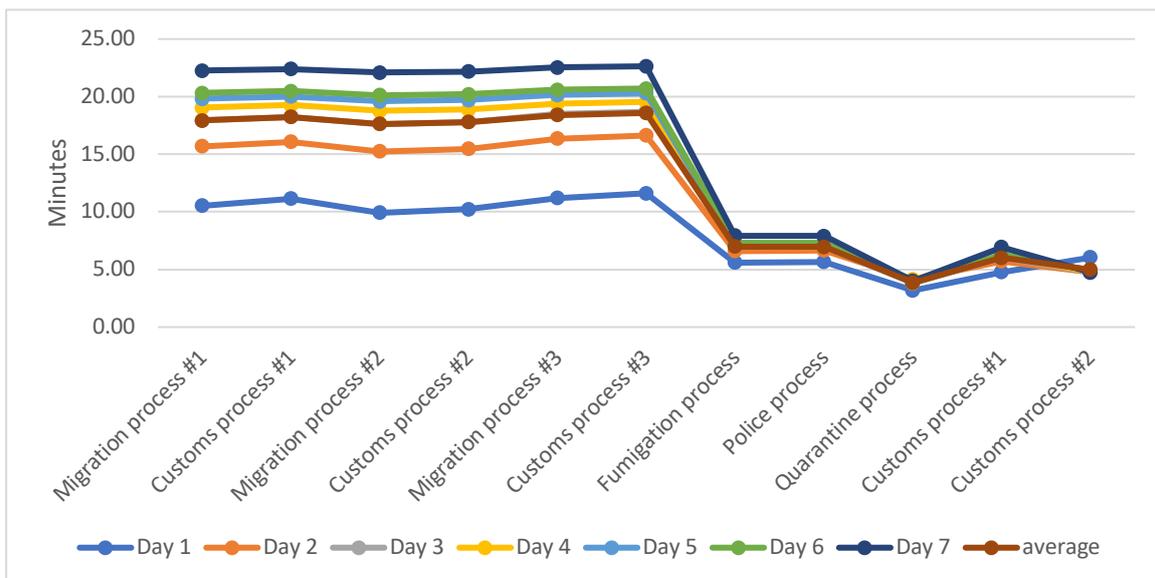
FIGURE 11.10.

Stay time of trucks per queue per day, in minutes



Source. Own Elaboration based on the simulation results.

FIGURE 11.11. *Stay time of trucks per server per day, in minutes*



Source. Own Elaboration based on the simulation results.

TABLE 11.4.
Stay time of trucks per process and queue per day, in minutes

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Ave
Queue to migration in CR	189.30	423.08	695.97	896.18	1071.18	1117.54	1255.55	806.97
Migration process #1 in CR	10.53	15.70	17.95	19.03	19.83	20.33	22.25	17.95
Customs process #1 in CR	11.15	16.09	18.23	19.26	20.01	20.48	22.39	18.23
Migration process #2 in CR	9.94	15.25	17.64	18.76	19.61	20.13	22.09	17.63
Customs process #2 in CR	10.23	15.46	17.80	18.89	19.71	20.22	22.17	17.78
Migration process #3 in CR	11.21	16.36	18.50	19.40	20.15	20.60	22.54	18.39
Customs process #3 in CR	11.61	16.63	18.69	19.55	20.28	20.71	22.64	18.59
Queue to gate in CR	222.17	295.85	326.48	339.09	348.87	354.49	361.81	321.25
Queue to fumigation in NI	54.22	65.01	69.47	70.77	72.19	72.92	76.28	68.69
Fumigation process in NI	5.60	6.60	7.01	7.13	7.26	7.33	7.92	6.98
Queue to police in NI	11.98	15.72	18.90	17.61	17.70	17.15	19.47	16.93
Police process in NI	5.65	6.66	7.00	7.10	7.22	7.30	7.90	6.98
Migration process in NI	3.18	4.14	3.82	4.13	3.94	3.82	4.00	3.86
Queue #1 to customs in NI	0.96	0.92	1.51	1.82	1.98	1.79	2.20	1.60
Customs process #1 in NI	4.77	5.73	6.04	6.18	6.26	6.33	6.93	6.03
Queue #2 to customs in NI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Customs process #2 in NI	6.05	4.77	4.77	4.81	4.92	4.92	4.74	5.00

Source. Own Elaboration based on the simulation results.

Simulation III

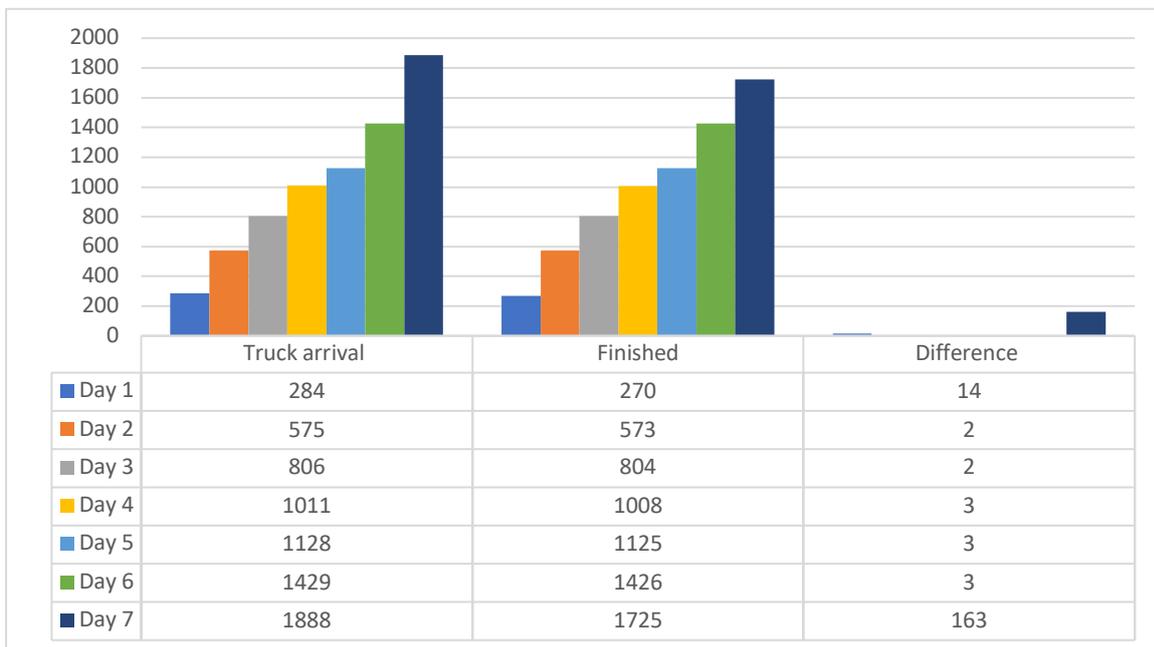
This Simulation III represents the Peñas Blancas land border post with the new Costa Rican infrastructure blueprint plus a new Nicaraguan lane to perform the fumigation, police, and migration controls to enter such country.

FIGURE 11.11 presents the accumulated number of trucks inputted into the process and the difference between the input and output of trucks after finishing the export and import process. When comparing FIGURE 11.7 from Simulation II and FIGURE 11.12, there is a substantial increase of trucks that have finished all the Costa Rican and Nicaraguan control processes in Simulation III. By the end of day 7, 1725 were processed in Simulation III versus 1314 trucks in Simulation II, this is an 31.3% increase in the capacity (411 more trucks). Furthermore, the difference between the number of trucks that arrive to the land border post

versus the number of trucks that concluded all the process has reduced substantially too. Day 7 has a higher number of unfinished trucks because is the day with the highest input of trucks (459 trucks) and there were trucks arriving to the queue when the land border post closed.

FIGURE 11.12.

Accumulated number of trucks arriving and finishing the process per day with double server for fumigation, police, and migration processes in Nicaragua, new Peñas Blancas blueprint

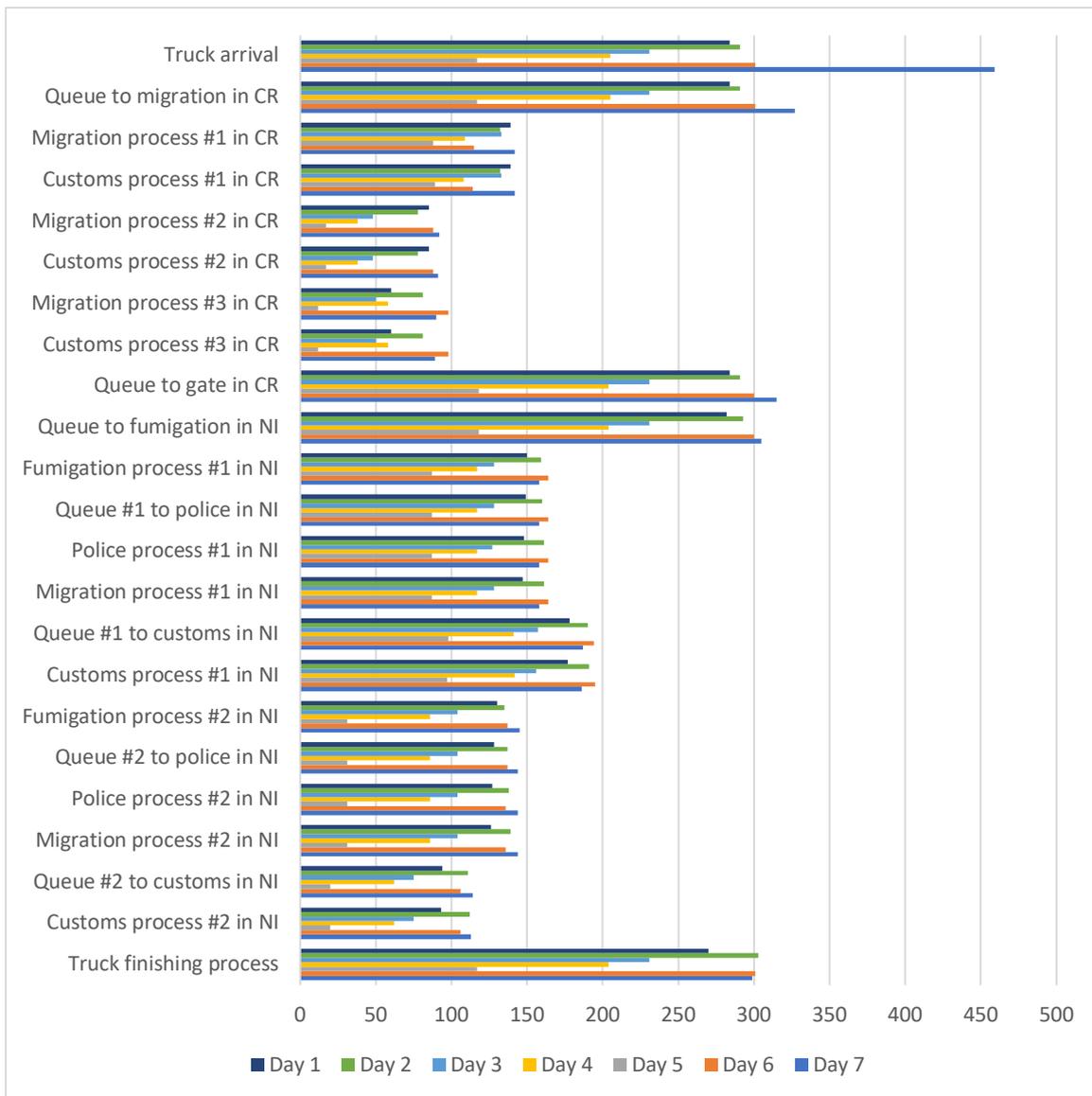


Source. Own Elaboration based on the simulation results.

FIGURE 11.13 presents the total throughput per day and per step of the whole import and export cycle. Day 1 is no longer the day with the highest throughput rate because all the queues and server remained fairly empty or idle throughout the Simulation III.

When looking at the number of throughputs in the single queues (“Queue to migration in CR”, “Queue to gate in CR”, and “Queue to fumigation in NI”) they are all very similar, which means that there is a very fluid movement of trucks along the process. Also, when comparing the latter queues to the total final throughputs (“Truck finishing process”) they are almost equivalent.

FIGURE 11.13.
Throughput per day, per queue and server



Source. Own Elaboration based on the simulation results.

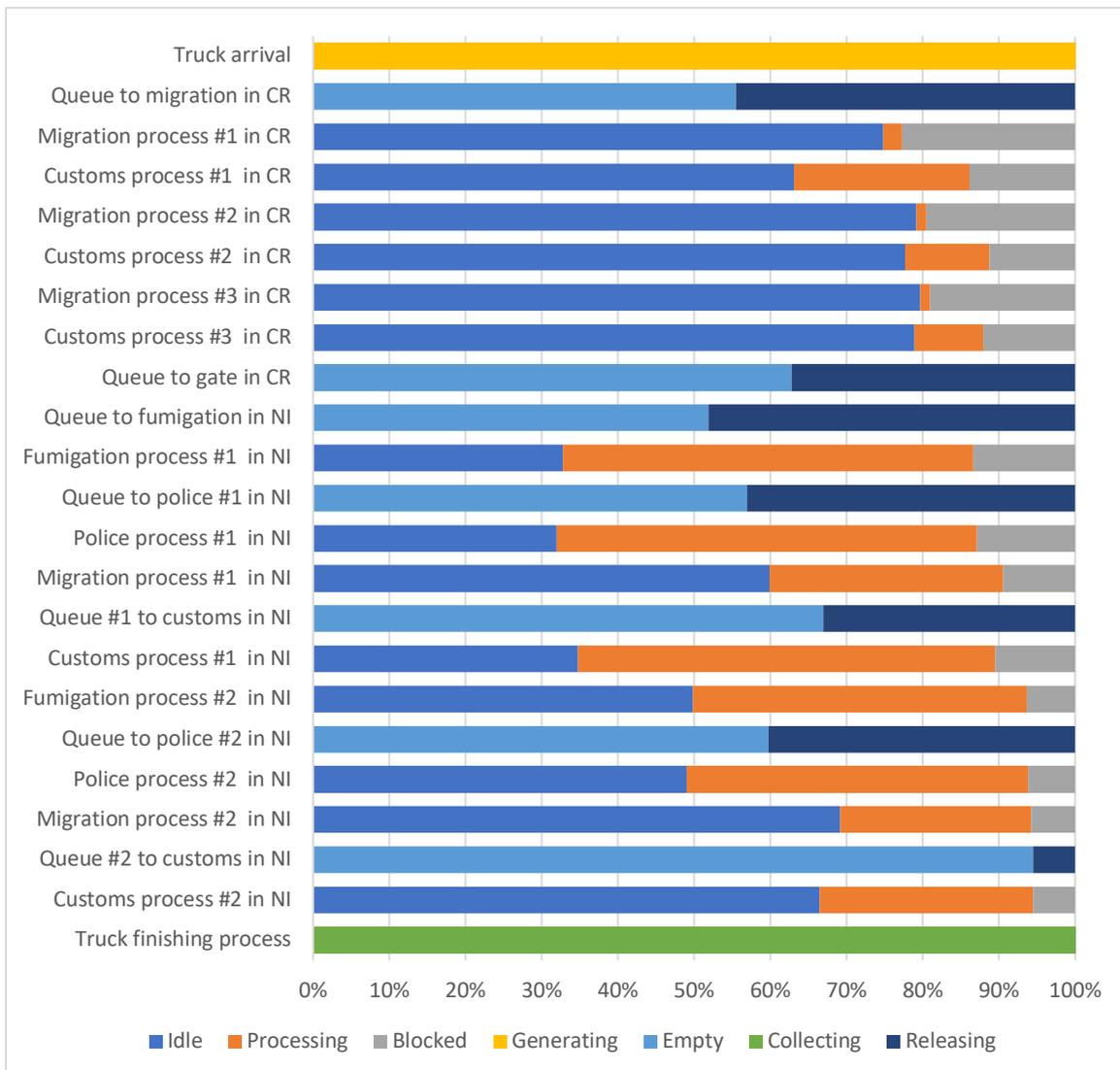
FIGURE 11.14 shows the average state per server and queue. The Costa Rican migration and customs processes are mostly “idle” and the “block” status has reduced significantly when compared to the previous simulations. For example, from an 86% blockage in the migration process on Simulation II, it has reduced to 23% and customs process blockage from 77% to 14%. The “block” status is also reduced in the Nicaraguan side. For example, the Nicaraguan customs process “block” status changed from 16% to 7.5%.

“Processing” state has increased for the Costa Rican migration and customs processes when compared to Simulation II. In the case of Nicaragua, the “processing” state is distributed among the new servers. The sum of the processing state per type of servers increased. For example, the fumigation process in Nicaragua has a processing rate of 73%, in Simulation III, there are two servers for such process, combined, they have a processing rate of approximately 99%.

All the queues are mostly “empty” instead of “releasing”, which means that many trucks go directly to the process instead of passing through a queue.

FIGURE 11.14.

Average state per queue and server



Source. Own Elaboration based on the simulation results.

TABLE 11.5 shows the maximum number of trucks that can be absorbed per queue and the number of trucks located in each queue at midnight per day. In this simulation, the queues are mostly empty every day. Day 7 has 132 trucks in the first queue because they arrive very near the closing of the border post as per the interarrival time.

TABLE 11.5.
Number of trucks in queues at midnight, per day

Object	MAX	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Queue to migration in CR	N/A	0	0	0	0	0	0	132
Queue to gate in CR	50	0	0	0	0	0	0	7
Queue to fumigation in NI	10	2	0	0	0	0	0	10
Queue #1 to police in NI	4	1	0	0	0	0	0	0
Queue #2 to police in NI	1	2	0	0	0	0	0	1
Queue #1 to customs in NI	1	1	0	0	0	0	0	1
Queue #2 to customs in NI	1	0	0	0	0	0	0	0
TOTAL QUEUE PER DAY		6	0	0	0	0	0	151

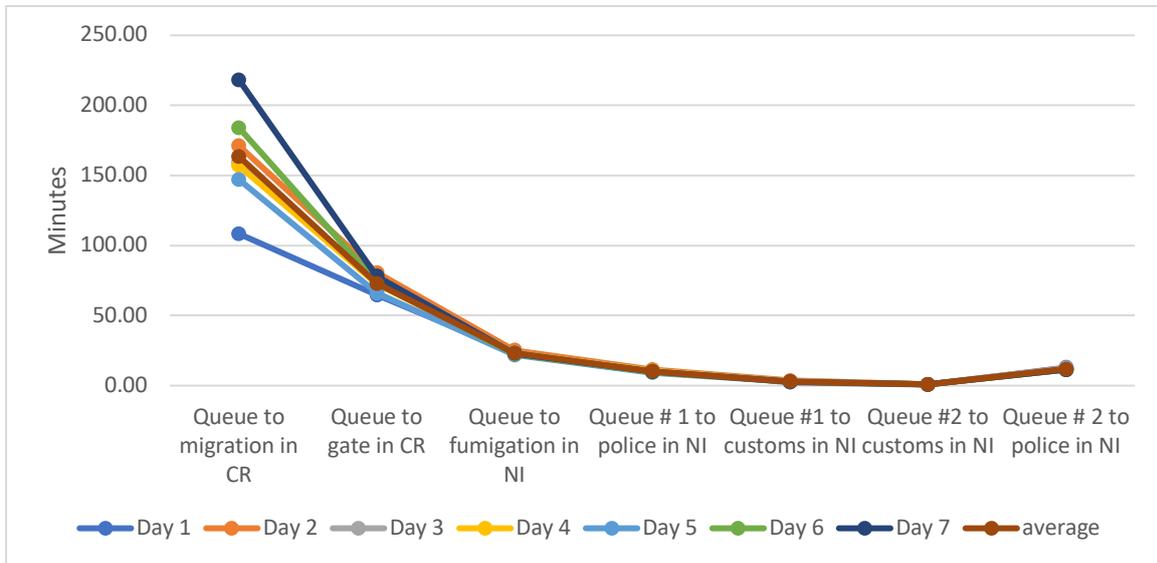
Source. Own Elaboration based on the simulation results.

FIGURE 11.15, FIGURE 11.16 and TABLE 11.6 present the average stay time of the truck per queue and server. In terms of queues, the total average stay time in queues is 4.6 hours.

The longest queue is still in Costa Rica, namely “queue to migration in CR” (2.7 hours in average) followed by “queue to gate in CR” (1.2 hours in average). These long stay time in Costa Rica is due to the capacity of the queues.

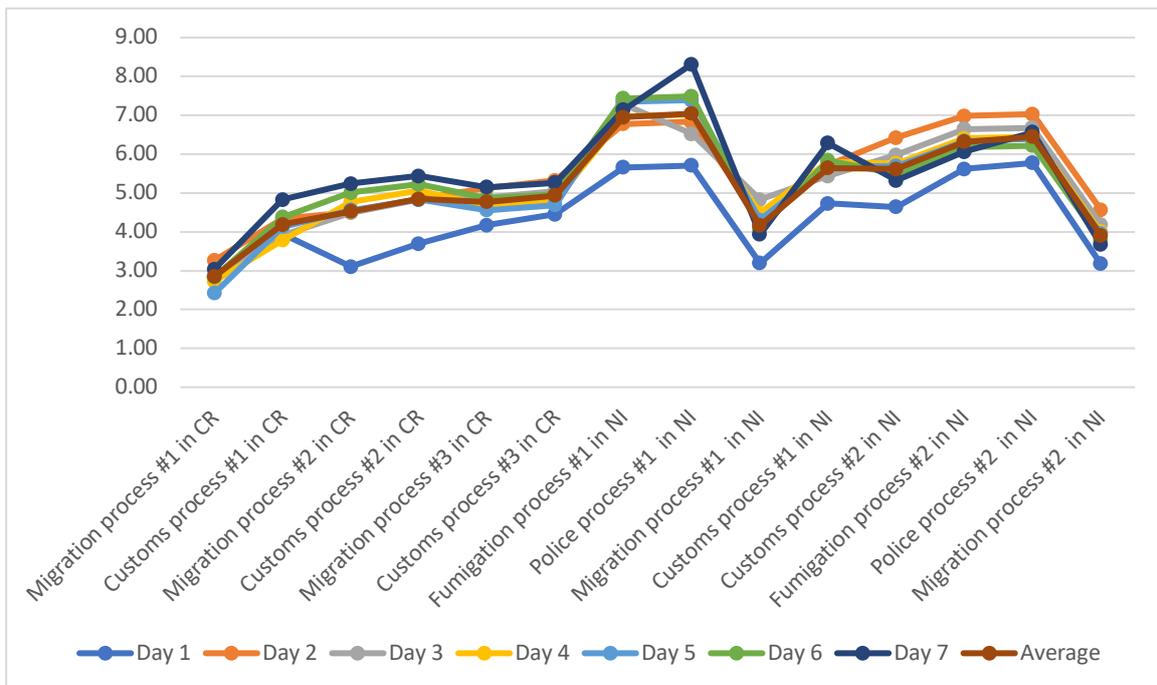
In terms of processes/servers, the two longest stay time are in Nicaragua, both of them are the police servers, one with 7.04 minutes and the other one 6.45 minutes. These two also have the highest “processing” state which may signifies that this might be the main bottleneck in the whole process. The following longest stay time of server are also in Nicaragua, specifically the fumigation servers #1 and # 2 with and average of 6.92 and 6.32 minutes, respectively.

FIGURE 11.15.
Stay time of trucks per queue per day, in minutes



Source. Own Elaboration based on the simulation results.

FIGURE 11.16.
Stay time of trucks per server per day, in minutes



Source. Own Elaboration based on the simulation results.

TABLE 11.6.
Stay time of trucks per process and queue per day, in minutes

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Ave
Queue to migration in CR	108.41	171.24	159.24	156.96	147.14	184.15	218.36	163.64
Migration process #1 in CR	2.84	3.26	2.83	2.73	2.42	2.83	3.04	2.85
Customs process #1 in CR	3.94	4.34	3.91	3.79	4.13	4.38	4.83	4.19
Migration process #2 in CR	3.10	4.50	4.50	4.77	4.56	5.01	5.24	4.53
Customs process #2 in CR	3.69	4.86	4.83	5.06	4.83	5.23	5.44	4.85
Migration process #3 in CR	4.17	5.12	4.88	4.67	4.56	4.86	5.15	4.77
Customs process #3 in CR	4.45	5.32	5.05	4.82	4.69	4.97	5.27	4.94
Queue to gate in CR	64.63	80.54	74.56	72.60	66.07	73.90	78.14	72.92
Queue #1 to fumigation in NI	23.88	25.23	23.74	23.16	21.78	22.46	22.87	23.30
Fumigation process #1 in NI	5.66	6.78	7.28	6.98	7.36	7.44	7.14	6.95
Queue #1 to police in NI	11.07	11.30	10.34	10.66	9.28	9.51	10.06	10.32
Police process #1 in NI	5.71	6.84	6.53	7.02	7.39	7.49	8.32	7.04
Migration process #1 in NI	3.19	4.36	4.83	4.48	4.31	4.08	3.93	4.17
Queue #1 to customs in NI	2.44	3.52	3.18	2.90	2.66	2.62	2.62	2.85
Customs process #1 in NI	4.73	5.72	5.44	5.81	5.68	5.84	6.28	5.64
Queue #2 to customs in NI	0.78	0.97	0.98	0.92	0.91	0.92	0.95	0.92
Customs process #2 in NI	4.64	6.43	5.98	5.76	5.69	5.50	5.33	5.62
Fumigation process #2 in NI	5.62	6.98	6.64	6.41	6.33	6.19	6.06	6.32
Queue #2 to police in NI	12.95	12.35	12.50	11.38	11.32	11.30	11.30	11.87
Police process #2 in NI	5.77	7.03	6.68	6.45	6.40	6.22	6.56	6.45
Migration process #2 in NI	3.17	4.57	4.19	4.00	3.95	3.78	3.67	3.91

Source. *Own Elaboration based on the simulation results.*