AGENT-BASED SIMULATION FOR PEDESTRIAN CROSSING THE BORDER FROM JUAREZ TO EL PASO

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Master's Program in Engineering

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AGENT-BASED SIMULATION FOR PEDESTRIAN CROSSING THE BORDER FROM JUAREZ TO EL PASO

by

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Declaration

This thesis/report is an output of the International Dual Master Degrees Program in Smart Cities Science and Engineering, a collaboration between Czech Technical University, Czech Republic, and The University of Texas at El Paso, USA.

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I declare that this Master's thesis is my own work and that I list all references in compliance with ethical guidelines on elaboration of Master's thesis.

I have no relevant reason against using this work in the sense of § 60 of Act No. 121/2000, on the copyright law.

El Paso, Texas, USA

May 11, 2022

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MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

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Study programme (field/specialization) of the student:

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Theme title (in Czech): **Simulace přechodu hranice Juarez - El Paso s využitím multiagentních systémů**

Theme title (in English): **Agent-based simulation for pedestrian crossing the border from Juarez to El Paso**

Guidelines for elaboration

During the elaboration of the master's thesis follow the outline below:

- Perform literature review on agent-based simulation with focus on applications in border crossing
- Analyze border crossing processes on the Ciudad Juarez - El Paso bridges
- Choose suitable software to perform the agent-based simulation
- Define scenarios for the simulation modelling
- Execute the simulation and discuss the results

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(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

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a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule
b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

L. S.

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I confirm assumption of master's thesis assignment.

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Student's name and signature

Prague .... May 3, 2022

Abstract

The border area of Ciudad Juarez, Chihuahua, Mexico and El Paso, Texas, the U.S. is connected by four land ports of entry. Pedestrian crossing the border from Ciudad Juarez to El Paso is the focus of this research. The objectives are to analyze the border crossing process and to develop a simulation model of the pedestrian border crossing at the Paso Del Norte Port of Entry. The literature review on this topic covers a description and explanation of the northbound border crossing process by foot. The simulation model development included data collection, followed by the coding of the model in the AnyLogic software. Subsequently, three scenarios representing three approaches to manage the number of inspection booths that serve the pedestrians were established and simulation experiments performed. The average waiting times and queue length at the inspection area were gathered from simulation runs and analyzed. Finally, recommendations to reduce the northbound pedestrian border crossing waiting time and possible future research on this topic are suggested.

Keywords: border crossing, port of entry, inspection area, pedestrians, simulation modeling, data collection, waiting time, AnyLogic

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Chapter 1: Introduction

The border crossing is a common process for residents within the area of El Paso, Texas, the U.S. and Ciudad Juarez, Chihuahua, Mexico. These two urban areas are connected by four main Ports of Entry (POEs) where the travelers and goods can cross the border. The northbound crossing is characterized by long waiting times and long queues at the POEs. Recently, the volume has slightly decreased despite the still ongoing COVID-19 pandemic. However, the volume of people crossing the border is expected to increase again. The purpose of this thesis is to observe, document, and subsequently simulate the pedestrian border crossing at the northbound direction of the Paso del Norte (PDN) POE. The scope of the thesis is to simulate three different scenarios of pedestrian border crossing at PDN POE, using the AnyLogic model.

1.1 Background

The thesis focuses on a specific POE along the U.S.-Mexico border. There are fifty POEs where people can cross the U.S.-Mexican border on land either by car or by foot. This international border, which follows the naturally created boundary, the Rio Grande river, has some of the busiest POEs between the United States and Mexico. Facilitated by these POEs, both border cities are collaborating with each other while supporting and developing its economic, technological, and social growth. The research focuses on the northbound crossing from Mexico to the U.S. The reason for concentrating on the northbound crossing is due to the border crossing policy that is applied by the U.S. government. The U.S. authorities have implemented document and security checks for all visitors and the U.S. citizens who cross the border seeking entry to the U.S. This action has created longer queues and travel delays for all the travelers.

The number of people crossing the border on foot is rather large (3,782,598 pedestrians per year 2021) [1] and there has not been much research done for this group of travelers. Thus, simulation modeling was done for northbound crossing of pedestrians. This study explores the bottlenecks of the process of border crossing by foot. Moreover, this research experimented with the possible adjustments of the POE's operations. The delay at border crossing is affected by many factors so even small modification of the POE infrastructure and operations may lead to significant change in travelers' experience. Simulation modeling is a good approach to explore several alternatives because it gives us an opportunity to study many different scenarios of particular problematics.

1.1.1 The El Paso-Ciudad Juarez International Border

There are four bridges that serve as POEs where travelers can move between Ciudad Juarez in Chihuahua and El Paso in Texas. Three of the bridges are located at or close to downtown of El Paso. The Ysleta-Zaragoza International Bridge, or Ysleta POE, is located on the eastern side of El Paso. The Bridge of the Americas (BOTA), or BOTA POE is between the Ysleta POE and the downtown of El Paso. The Stanton Street Bridge or Stanton POE, and The Paso del Norte (PDN) International Bridge or PDN POE are both in the downtown area. The PDN POE has been selected as the research site in this thesis because it is the busiest of the four POEs in terms of pedestrian traffic. The high volume of pedestrian traffic at the PDN POE is due to its location because it connects the central business districts of both cities and therefore it serves as the gateway for economic and social interconnections between the two cities and their residents [2].

1.1.2 Border Crossing at Paso Del Norte Port of Entry

As has already been mentioned, the PDN POE has been selected as the study site. This subsection describes the existing operations at this POE. The information on the POE operation was extracted from the report of the International Bridges Crossborder Survey (IBCS), that was created in a collaboration between the City of El Paso's International Bridges Department and El Colegio de la Frontera Norte. This is an annual survey for monitoring social and economic impacts of cross border activities both for vehicle and pedestrian crossings [3]. The results presented in the report are outputs from the surveys done during October 1, 2019 to March 17, 2020. The surveys were performed at the PDN, BOTA and Ysleta POEs. Although the results are provided for all the three POEs together, it can be used to represent the pedestrians who used the PDN POE.

The IBCS offers findings regarding demographic profiles, reasons for crossing, spending by economic activities and trip characteristics. The most interesting results for the purpose of this thesis are the reasons for crossing. About 40 % of the northbound cross border travelers came to El Paso to shop. The next two major reasons for crossing the border were related to job or school, which makes up around 25 % of the northbound trips. Social visits accounted for about 28 %. The less common trip purposes were healthcare related visits, drop offs and pick-ups and vacation related trips [3]. This overall percent distributions apply to both pedestrians and drivers of the passenger cars. Table 1.1 shows the distribution of trip purposes for pedestrians crossing the border in the northbound direction [3].

Table 1.1 – Trip purpose for northbound crossings.

Reason	Distribution in %
Shop	37.8
Social	28.3
Work related	17.7
School related	6.4
Drop off/pick up	2.7
Eat/drink	1.5
Health visit	1.3

Based on the study [2] and observation, the PDN is the most used POE by pedestrians. However, the annual volume of pedestrians crossing the border over this bridge has shown a decreasing trend in the past twenty years. As can be seen on the Figure 1.1, the volume of pedestrians has been decreasing for a few years now with only a slight sign of increase during the years 2014 to 2016. The overall drop may have several reasons, including the long waiting time at the POE. Obviously, the last two bars for the years 2020 and 2021 are showing a significant fall in the volume due to the international travel restrictions imposed by the U.S. government during the COVID-19 pandemic [1].

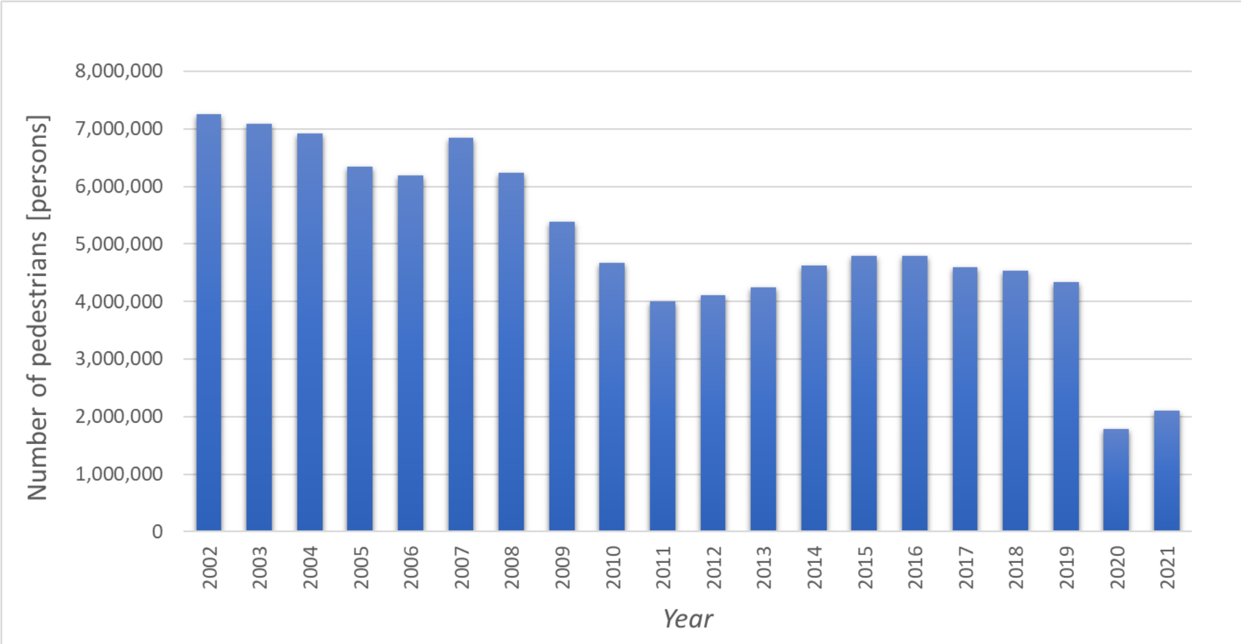

Figure 1.1 – Annual number of the pedestrians crossing northbound at the Paso Del Norte Port of Entry (data from [1]).

1.2 Thesis Objectives

This thesis has several objectives.

The first objective is to provide the background of the POEs at the El Paso-Ciudad Juarez border, and document the process of pedestrians crossing in the northbound direction from Ciudad Juarez into El Paso.

The second objective is to document and present the publicly available data, their sources on northbound pedestrian crossing at the PDN POE. Additional data will be collected if necessary.

The third objective is to develop a simulation model of the northbound pedestrian border crossing inspection process at the PDN POE.

Finally, the fourth objective is to use the simulation model to analyze the possible bottlenecks of northbound pedestrian border crossing process and based on the analysis provide a possible recommendation that could reduce the waiting time.

1.3 THESIS OUTLINE

Chapter 1 is the introduction to the border crossing problem and provides description of the thesis objective and thesis outline.

Chapter 2 is the review of the research area and the detailed introduction of the process of the pedestrian border crossing from Ciudad Juarez to El Paso. This chapter includes a background of the ports of entry and the inspection service provided at the inspection area.

Chapter 3 focuses on the description of the software tool used for the simulation modeling and explains the designed model itself together with description of the different scenarios.

Chapter 4 clarifies the simulation outputs and type of data retrieved from AnyLogic.

Chapter 5 analyzes obtained outcomes from the simulation model and compares it across the designed scenarios and also with the collected data during the research.

Chapter 6 gives the conclusion of the research presented in the thesis together with the summary of the results. Moreover, it provides recommendations for the pedestrian border crossing from Ciudad Juarez to El Paso at the Paso del Norte POE based on the simulations' outcomes and suggestions for possible future research in this topic.

Chapter 2: Border Crossing at El Paso

The goal of this chapter is to review the border crossing system in El Paso which is the first objective. This chapter covers the background of the POEs together with brief descriptions of the processes of border crossing.

2.1 BACKGROUND OF PORTS OF ENTRY

The PDN POE is located at 1000 S El Paso Street on the U.S. side and on Avenue Benito Juarez on the Mexican side. The location of the bridge is displayed in the map below (Figure 2.1) [4]. It was built in 1800s and was opened in 1898. This bridge is owned and managed by the City of El Paso International Bridges Department in the U.S. side. In the Mexican side, the owner is the Federal Government of Mexico, and it is operated by Caminos y Puentes Federales de Ingresos y Servicios Conexos. It consists of four lanes for non-commercial traffic only for the northbound direction and for pedestrian crossing in both the northbound and southbound directions. The POE is opened 24 hours a day for privately owned vehicles (passenger cars) and pedestrians [5].

Figure 2.1 – Location of the Paso Del Norte Port of Entry.

The Stanton POE, also known as The Good Neighbor International Bridge or The Friendship Bridge, is located at 1001 S Stanton on the U.S. side and at Avenue Lerdo on the Mexican side. The location of the bridge is displayed on the map below this text (Figure 2.2) [4]. This bridge's construction was completed in 1967. The owner of the bridge is also the City of El Paso. It is managed by the City of El Paso International Bridges Department. On Mexican side, the owner is the Federal Government of Mexico. The bridge leading to the POE in the north side has four lanes. Three of the lanes are for southbound passenger vehicles and the last one is a SENTRI lane also known as Dedicated Commuter Lane (DCL). This type of special lanes will be described later. This POE also serves non-commercial traffic. The POE is opened from 6:00 a.m. to 12:00 a.m. on weekdays and from 8:00 a.m. to 12:00 a.m. on weekends for privately owned vehicles (POV), i.e. passenger cars [5].

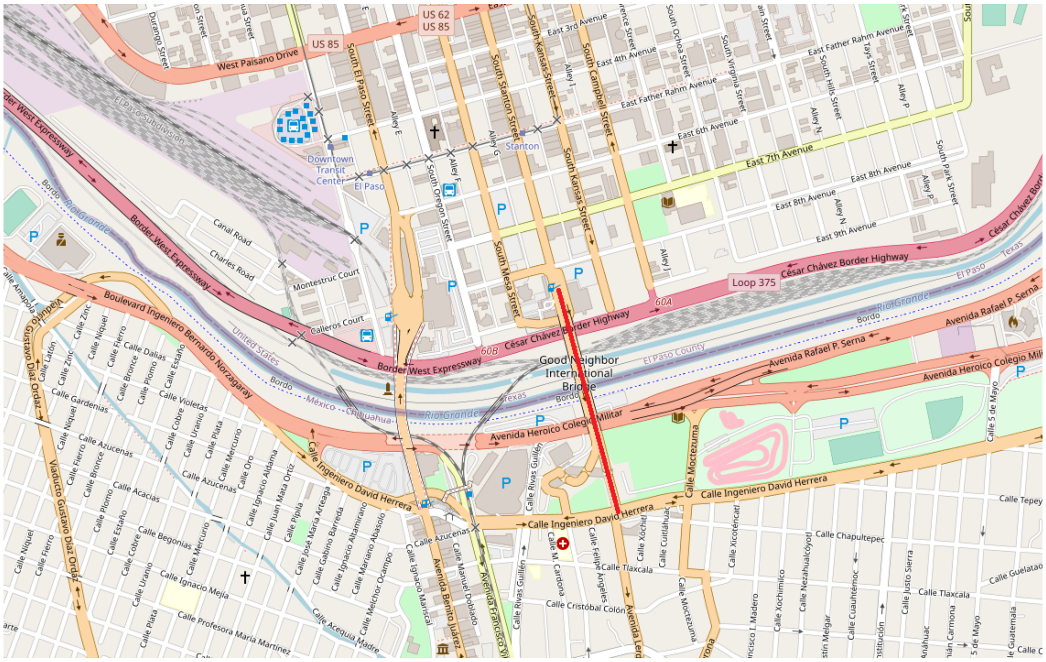

Figure 2.2 – Location of the Stanton Port of Entry.

The Bridge of the Americas POE, abbreviated BOTA POE, also known as Puente Libre or Puente Internacional Córdova-Las Américas, is located at 3600 E Paisano Dr on the U.S. side and at Avénida dé las Américas 2551, Margaritas, on the Mexican side [6]. The BOTA POE is a complex of international bridges that are actually separate structures. The location of the bridge is displayed on the map below (Figure 2.3) [4]. The beginning of construction of the BOTA dated back to the year 1996 with June/July of 1998 as a date of completion. Later in 1993, the International Boundary and Water Commission (IBWC) decided to reconstruct the bridge due to possible risk condition of the structure. The owner of the BOTA on the U.S. side is the U.S. Section of the IBWC. On Mexican side, the owner is the same section of Ciudad Juarez, also the IBWC. Operation of the BOTA is under U.S. Customs and Mexican Customs. As mentioned above at the beginning of the paragraph, the BOTA is a group of bridges. It consists of four separated parts, two bridges for commercial traffic and two bridges for other traffic including passenger vehicles and pedestrians. The bridges for truck traffic have two lanes at each bridge which make up four lanes for commercial traffic in total. And the second pair of bridges provide four lanes at each of the bridges which makes eight lanes for passenger vehicles in total and two lanes for pedestrians. The entire complex is either way for northbound and southbound traffic [5]. Besides general lanes, there are FAST lanes for commercial traffic and Ready lanes for passenger vehicles, both for northbound traffic. At the BOTA there is no SENTRI lane [1]. The BOTA is open 24 hours for passenger vehicles. The operating hours for commercial traffic differ for weekdays and weekends. From Monday to Friday, the BOTA is open from 6:00 a.m. to 7:00 p.m. and on Saturday from 6:00 a.m. to 2:00 p.m., on Sunday it is closed [5]. This is the only international bridge in El Paso that does not have a toll charge [7].

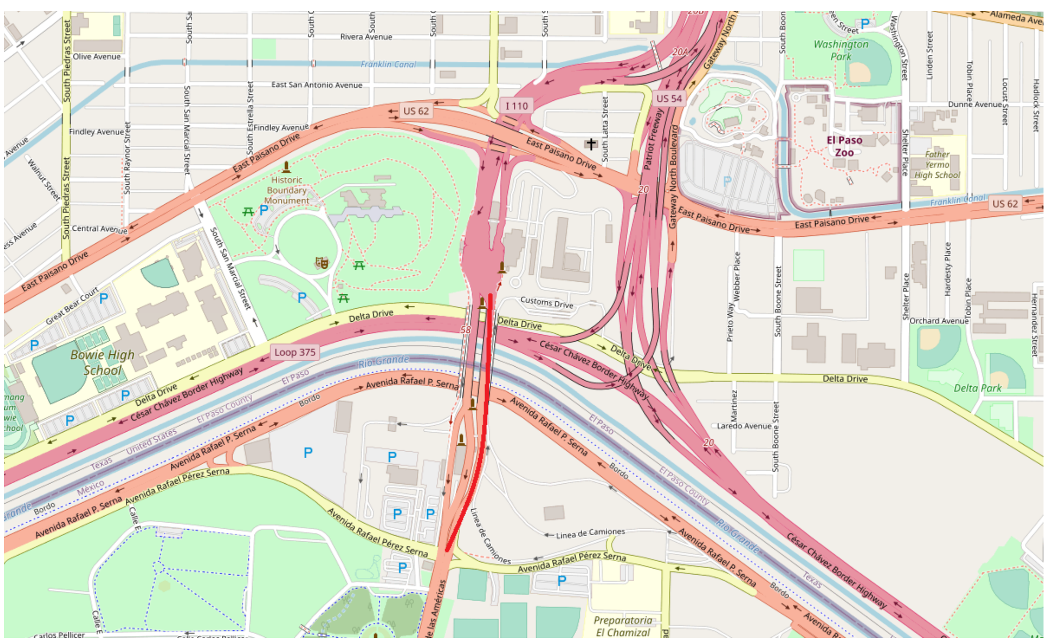

Figure 2.3 – Location of the Bridge of the Americas Port of Entry.

Finally, the Ysleta Bridge, also known as Ysleta-Zaragoza or Zaragoza Bridge, is located at 791 S. Zaragoza on the U.S. side and at Av. Waterfill on the Mexican side. The location of the bridge is displayed on the map below (Figure 2.4) [4]. The original construction of the bridge is dated back to 1938 and has been reconstructed in 50s and 90s since then. The Ysleta bridge consists of two separated constructions which has been done during the last renovation in 1990. Similarly, as at the BOTA, one part serves for truck traffic and the other serves for passenger's vehicles and pedestrians. The commercial traffic can use up to four lanes on one bridge and non-commercial traffic up to five lanes on the second bridge. Besides the five lanes for POV, there are two paths for pedestrians [5]. Two of the five lanes are for northbound traffic, next two are for southbound traffic and one lane is the SENTRI lane also known as DCL. The bridge for commercial traffic has each two lanes for northbound and southbound traffic but one of the northbound lanes is FAST lane. The owner of the Ysleta bridge on the U.S. side is the City of El Paso, and it is managed by the City of El Paso International Bridges Department [8]. On the Mexican side, the owner is Government of Mexico, and it is managed by Aminos y Puentes Federales de Ingresos y Servicios Conexos. The Ysleta bridge is opened for POV and pedestrians 24 hours a day same as the SENTRI lane is. The commercial part of the bridge is opened from Monday to Friday from 6:00 a.m. to 12:00 a.m., on Saturdays from 8:00 a.m. to 4:00 p.m. and is closed on Sundays [5].

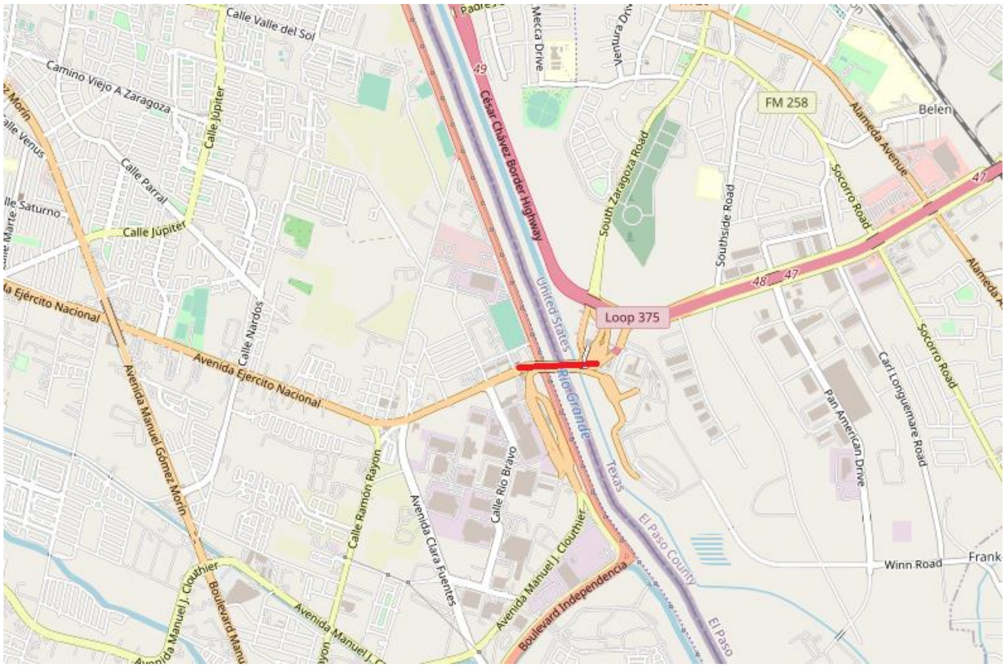

Figure 2.4 – Location of the Ysleta Port of Entry.

Table 2.1 summarizes all the northbound inspection booths at the four POEs [9]. The table shows if there is a lane for commercial traffic and if so, how many inspection booths are there and how many of them are FAST lane. The same applies for non-commercial traffic. The lanes for non-commercial traffic are further divided into Ready or SENTRI lanes. The number or these special lanes are not specified in the table because they vary.

The last column in the first row of the PDN bridge contains important information for the subsequent simulation model. Based on the number of booths, the model infrastructure is created.

Table 2.1 – Number of the northbound inspection booths.

	Commercial traffic		Non-Commercial Traffic			
			POV		Pedestrian	
	General	FAST	General	Ready/ SENTRI	General	Ready/ SENTRI
PDN	-	-	12	YES	14	YES
Stanton	-	-	3	YES	-	-
BOTA	6	YES	14	YES	4	YES
Ysleta	10	YES	12	YES	4	NO

2.1.1 Special lanes

For better orientation, below is a brief explanation of special lanes that may be either FAST, Ready or SENTRI. These definitions have been cited from Texas-Mexico International Bridges and Border Crossings Report [5]. Additional information about travelers' programs that accelerate the process of border crossing for all pedestrians, passenger cars and commercial traffic is added based on The Department of Homeland Security website (source 11).

Besides using the described traveler's programs for speeding up the process of the border crossing, the pedestrians can use one more service offered. There is a public service called TransBorde which is a bus line with route among Ciudad Juarez and El Paso [10]. Passengers arrive straight to the inspection area by bus without waiting in the bridge lane. Once they enter the inspection area, they proceed to wait in the certain lane like the rest of the pedestrians.

Trusted Traveler Programs

Trusted Traveler Programs are programs that allow members to use special lanes at the POEs to simplify and accelerate the process of international border crossing [11]. All the memberships are valid for period of five years, and they differ in attributes, price and membership eligibility. There are five basic programs:

- TSA PreCheck
- Global Entry
- NEXUS
- SENTRI
- FAST

TSA PreCheck applies only to trips done by air transport. The most common programs for crossing the U.S.-Mexico border are SENTRI and FAST. FAST means Free and Secure Trade and it is a bilateral initiative between the U.S. and Mexico designed to ensure security and safety while enhancing the economic prosperity of both countries [5]. FAST program applies to commercial traffic. The most common and the most important trusted traveler program for pedestrians is SENTRI. The Ready lane is closely related to SENTRI program.

SENTRI program and Ready lanes

SENTRI means Secure Electronic Network for Travelers' Rapid Inspection. It is a program for frequent travelers who voluntarily undergo a background check in order to receive expedited treatment [5].

SENTRI is a U.S. Customs and Border Protection (CBP) program that allows expedited clearance for pre-approved, low-risk travelers upon arrival in the U.S. Participants may enter the

U.S. by using dedicated SENTRI lanes at the southern land POEs. Travelers must be pre-approved for the SENTRI program. All applicants undergo a rigorous background check and in-person interview before enrollment [12].

The eligibility for SENTRI program applies for U.S citizens, U.S lawful permanent residents and all foreign nationals who travel by air or land. The five-year membership fee is $122.25 USD (dated 1/27/2022) [11].

Ready lanes are special lanes that use Radio Frequency Identification (RFID) technology embedded in certain documents to speed up the border crossing process. Travelers with RFID-enabled travel documents (U.S. Passport Cards, Enhanced Driver's Licenses, Enhanced Tribal Cards, Enhanced Border Crossing Cards, Enhanced Permanent Resident Cards, and Trusted Traveler Program (NEXUS, SENTRI, Global Entry or FAST cards [13]) can hold up their document to a sensor that will send the information to primary inspection officers [5].

SENTRI lane operates as Dedicated Commuter Lane (DCL), and it requires specifically SENTRI card which is part of the Trusted Traveler Program, and no other cards are accepted there [1].

To sum up, SENTRI cards and other RFID cards are accepted in the Ready lanes, but the SENTRI lane will only accept the SENTRI card [1].

2.2 Process of Border Crossing

Crossing the border from Ciudad Juarez to El Paso is possible by vehicle or on foot. This thesis focuses on modeling the pedestrians border crossing activities and therefore the background of crossing by walking is specified in this section. This section explains the terminology used, the process of pedestrian border crossing including the actors and services involved in the process.

2.2.1 Terminology

In this thesis, following distinguishable terminologies have been used.

- **Bridge Lane** is the part of the pedestrian lane that is on the bridge. A bridge lane extends from the origin on the Mexican side to the area where a pedestrian waits to be admitted to the inspection area on the U.S. side.
- **Lane** refers to a lane in the building that leads to inspection booths. In this lane, a pedestrian waits to be asked to come to the inspection officer.
- **Inspection Booth** is the area where a pedestrian's documents are checked by a CBP officer.
- **Primary Inspection** is the term used to describe the main inspection process.
- **Secondary Inspection** is the term used to describe the potential additional inspection process which may occur after the Primary Inspection.
- **Inspection Area** is the area (building) where inspections are held. An Inspection Area consists of Lanes and Inspection Booths for Primary Inspection and Secondary Inspection.
- **Release Area** is used for the area where a pedestrian passes the inspection process and is admitted to the U.S.

2.2.2 Actors

Before the interpretation of the process of border crossing, important groups of participants will be stated. The actors include the owners of the bridges, operational administrators, and users, (pedestrians).

The U.S. Customs and Border Protection (CBP) is one of the most known and without doubt one of the most important organizations at the border. The CBP is the biggest component under the U.S. Department of Homeland Security which has a responsibility of keeping the U.S.

homeland and its citizens safe while assuring a smooth international trade and travel. The CBP operates under five permanent mission priorities: counter terrorism, combat transnational crime, facilitate lawful trade and protect revenue, facilitate lawful travel, and especially securing the border. This priority is stated as follow: “Protect the Homeland though the air, land and maritime environments against illegal entry, illicit activity or other threats to uphold national sovereignty and promote national and economic security” [14].

One component of CBP is the U.S. Border Patrol which is the enforcement arm responsible for securing the U.S. borders between the POEs. The Border Patrol’s mission is to secure and prevent illegal entry to the land of the U.S. The agents of the Border Patrol are responsible for detecting and securing thousands of miles of U.S.-Mexico and U.S.-Canada borders [14].

The office in charge of customs and border protection on the Mexican side is called La Administración General de Aduanas (AGA). This federal organization is responsible for monitoring and controlling the entry to the country while remaining in compliance with national security. The next objective of the AGA is to ensure the public health and the environment and protect the country from dangerous or illegal merchandise flow [15].

The City of El Paso and the Federal Government of Mexico are the owners of three out of the four bridges, i.e., the PDN bridge, Stanton bridge and Ysleta-Zaragoza bridge. The owner of the Bridge of the Americas is a federal government agency called International Boundary and Water Commission (IBWC) [5].

The IBWC is a group established based on the agreement between the federal governments of the U.S. and Mexico. Each country has its own section of the IBWC. The U.S. Section of the IBWC resides in El Paso and the Mexican Section in Ciudad Juarez [16].

Next, another organization should be mentioned. Although it is not a body in charge of security or maintenance of the border infrastructure, the Bureau of Transportation Statistics (BTS) collects transportation data at the border. This statistical data is important for transportation planning and decision making [17].

Last but not least, the users who are not only pedestrians but all drivers and passengers of personal vehicles and commercial vehicles, are also actors. In 2021, the four POEs in El Paso-Ciudad Juarez served 3,782,598 pedestrians, 8,932,876 passenger cars and 847,173 trucks that crossed in the northbound direction [1].

2.2.3 Services

This subsection describes the processes of border crossing in the northbound direction. The border crossing processes may be distinguished in several ways. The processes are different for commercial traffic and non-commercial traffic. Non-commercial crossing may be by passenger vehicle or as a pedestrian. For the purposes of this research, only pedestrians' point of view is considered and subsequently described.

Firstly, the primary inspection for pedestrians is explained in detail. Then, the secondary inspection process for pedestrians is described. Although the simulation model focuses mainly on the inspection area of the primary inspection, the secondary inspection has to be defined as well. The potential process of declaration of goods is explained in the end.

Once a pedestrian enters a bridge lane and walks towards the U.S., after crossing the actual border, the first document check is held. There are usually two CBP officers at the bridge lane who ask every pedestrian to show the identity document (such as passport, and/or visa). This is the first control to remind the pedestrians that each of them should have identification document. There is no waiting time for this initial check as people are passing by the CBP officers while showing their documents without stopping.

Once a pedestrian arrives at the inspection area, the pedestrian has to choose the lane to go to. In the PDN bridge's inspection area, there are four types of lanes. The general lane serves all types of users. The SENTRI lane serves pedestrians who are enrolled in the SENTRI Program. Also, there may be a lane dedicated only for university or high school students. The last type of lane is for pedestrians who require special assistance, such as disabled people or people on wheelchairs.

Later, when a pedestrian reaches the inspection booth, the inspection processes for the different lanes are the same. The only difference is the extent of the inspection of the documents. The CBP officer at the inspection booth asks for an identity document including a visa if required. The document is either a passport or a SENTRI card. While checking the documents, the CBP officer may ask questions about the purposes of travel. In the end, the CBP officer asks if the pedestrian has anything to declare. If the pedestrian has nothing to declare, the CBP officer returns the documents, and the entry is approved. The pedestrian can leave the area of the inspection booth. This is the smoothest scenario that involves only the primary inspection. If the pedestrian has something to declare, he/she has to present the goods to the CBP officer. If the goods include alcohol, then the pedestrian is sent to the Texas Alcoholic Beverage Commission booth and pays the import tax. The last scenario that can occur is when the identity document or any part of the required documentation is not satisfactory. If the pedestrian is not a U.S. citizen and there is an issue with the travel document, the CBP officer sends the pedestrian to the secondary inspection area. The CBP officer from the primary inspection passes on the pedestrian's documents to another

CBP officer who is responsible for the secondary inspection. The pedestrian leaves the area of the primary inspection and goes to the area of the secondary inspection.

The secondary inspection is more like an interview between the CBP officer and the pedestrian. Additionally, the CBP officer can ask for x-ray inspection of belongings of the pedestrian. If the CBP officer is satisfied with documents and answers, the pedestrian can leave the area of the secondary inspection and is approved to enter the U.S. Otherwise, if the CBP officer detects any issue, the pedestrian's entry is denied and is asked to return to Mexico. If the pedestrian successfully passes the primary or secondary inspection, he/she has to place his/her belongings, such as handbag or backpack, on an x-ray machine. After picking up their properties at the other end of the x-ray machine, the pedestrian leaves the inspection area and enters the U.S.

Figure 2.5 provides a look into the inspection area on the PDN bridge where pedestrians are waiting in the lanes [18].

Figure 2.5 – Paso Del Norte Port of Entry pedestrian inspection area. [Photo from: KTSM Photo/Raul Martinez]

2.2.4 Graphical representation

Figure 2.6 presents the northbound pedestrian border crossing process beginning with the bridge lane from the Mexican side to the time when a pedestrian reaches an inspection booth for the primary inspection. Figure 2.7 continues the northbound border crossing process which includes the primary inspection, secondary inspection, and customs declaration.

Because of the scope of the thesis, the flowcharts focus on the border crossing from pedestrian's point of view. A flowchart operates with few symbols. An oval, or a terminator, represents a starting or ending point. A rounded rectangle represents a process or a state. A diamond shaped element represents a decision node. In these flowcharts, the decision is either yes or no. Arrows show the direction of the connections in the flowchart.

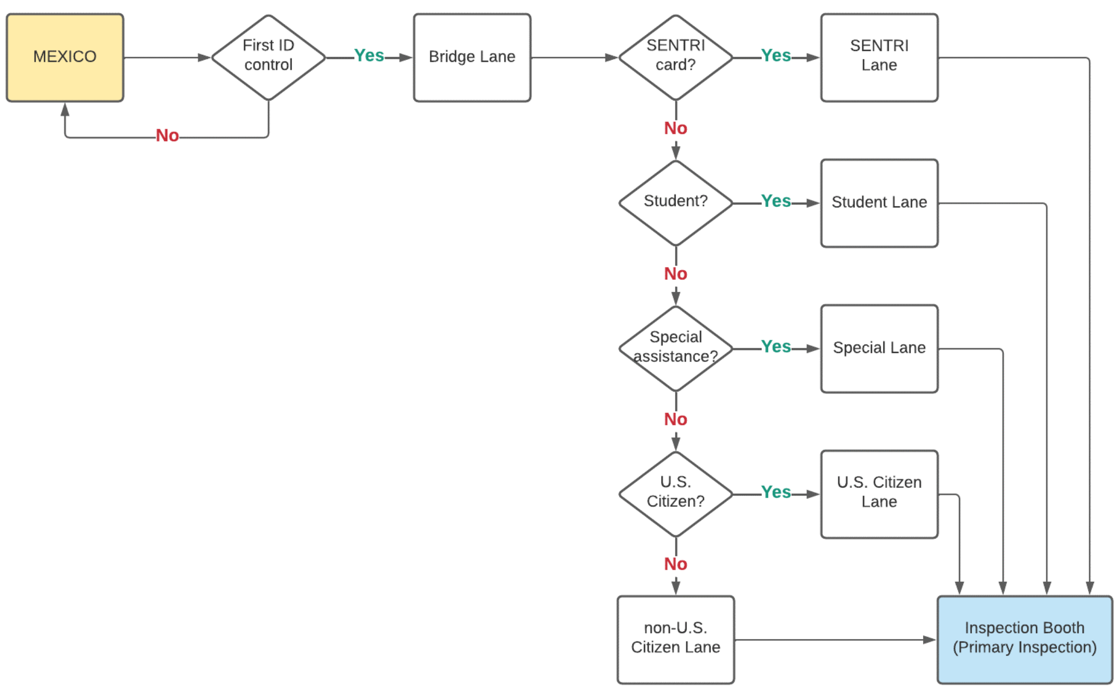

Figure 2.6 – Flowchart of northbound pedestrian border crossing – from the bridge lane to the inspection booth.

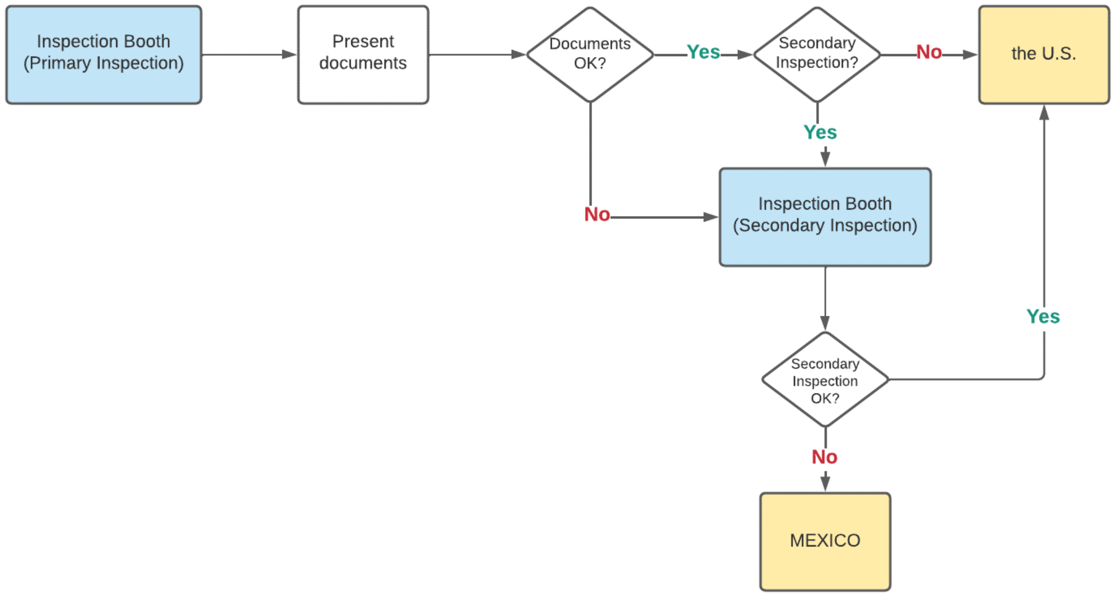

Figure 2.7 – Flowchart of northbound pedestrian border crossing – primary and secondary inspection.

Chapter 3: Simulation Modeling

One of the objectives of the thesis is to develop a model to simulate pedestrians crossing the border from Ciudad Juarez, Chihuahua, Mexico to El Paso, Texas, the U.S. For this part of the thesis, the northbound pedestrian crossing at the PDN POE has been chosen. The model has three scenarios that are distinguished later in the following sections of this chapter. Evaluation of the simulation results followed by a recommendation for management of the pedestrian border crossing are provided in Chapters 5 and 6 respectively.

The reason of choosing the northbound pedestrian crossing at the PDN POE is because (1) it has the highest volume of pedestrians among the four POEs in El Paso, Texas; (2) it is located at a convenient location right in the downtown; and (3) more data for border crossing are available to the public.

3.1 Simulation Software

The tool used for the simulation modeling is called AnyLogic. This simulation software tool allows users to implement three simulation modeling approaches: system dynamics, discrete event, and agent-based modeling [19]. The last one, agent-based modeling is used for this thesis. This method is the least abstract in comparison to the other two approaches. AnyLogic has many libraries which contain the most commonly used objects. For the project and its scope, it is easy for a user to use appropriate built-in libraries with suitable behavior to create a good base model for the simulation. AnyLogic allows a use of different libraries in one simulation.

The agent-based modeling approach operates with agents and their behavior that are set in particular environment where the agents are connected [20]. The agents are simple active entities, with assigned behavior. The agent can be either an independent individual entity or a defined group, e.g., of people, of households, of vehicles [20]. During simulation runs, agents actively move to accomplish their defined mission. The agents must respect all rules among each other, and rules of the simulation itself (e.g., forbidden areas, average times for a process, etc.). The required outputs are set by the creator of the simulation model. These outputs can have many forms, from simple numeric tables to complex charts.

Figure 3.1 and Figure 3.2 display examples of simulated environment in AnyLogic [19]. Figure 3.1 is a model of an airport security checkpoint with a logic flowchart below. Figure 3.2 is a screenshot during the simulation run.

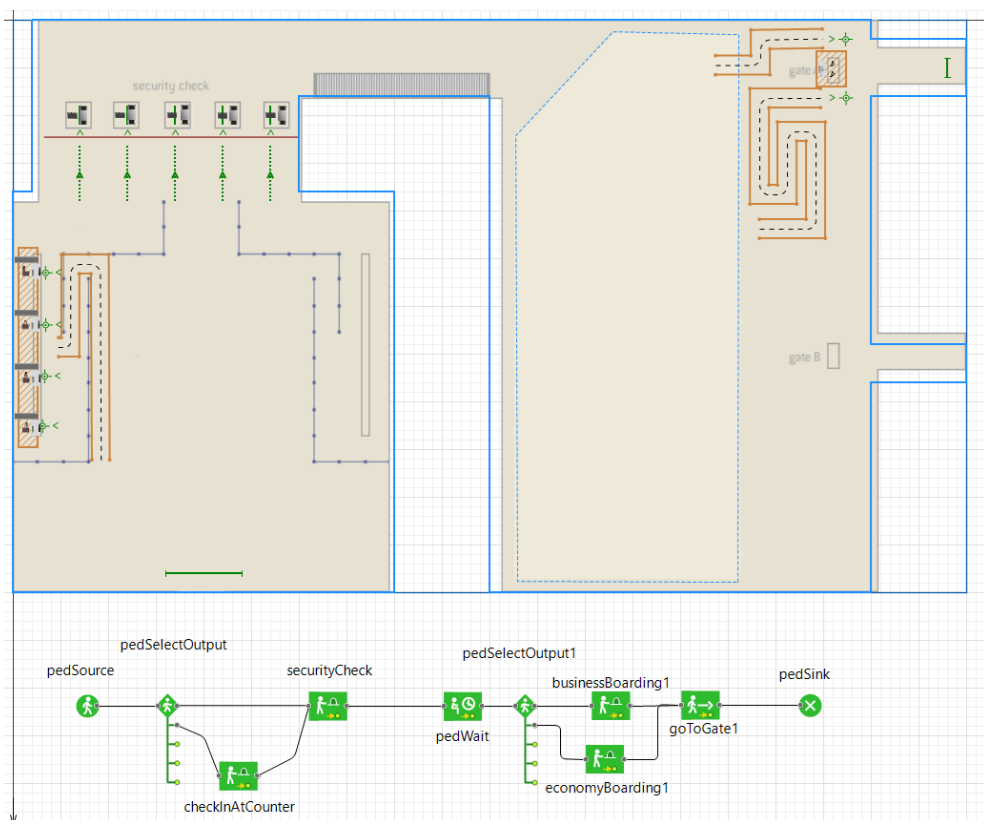

Figure 3.1 – Example of AnyLogic environment – plan view and logic flowchart.

Figure 3.2 – Example of AnyLogic environment – screenshot.

AnyLogic simulation has been used in industries such as manufacturing, transportation, warehouse operations, logistics, supply chains, healthcare, asset management and marketing [20]. Among the AnyLogic users are Google, Volkswagen, Ford, DHL, Pfizer, and Vodafone. Many case studies have been done in the above-mentioned industries and users. Very few pedestrian or passenger-focused models have been found. For example, the company Fraport AG that is operating terminals at several major international airports, developed an airport passenger flow simulation model in AnyLogic for the Frankfurt airport to forecast passenger movements [21]. In 2018, the biggest rail network operator in Russia developed simulation models to analyze the capacity and bottleneck at 31 railway stations. The outputs were used to prepare changes in timetable or train type and number of carriages [22].

3.2 Data Collection

The data used to develop the pedestrian simulation model in the AnyLogic were collected manually by two methods. The first method was structured interview. Prior to the interview, the author completed a course on Human Subject Research administered by the UTEP Institutional Review Board (IRB) [23]. The IRB was the unit in UTEP charged with implementing policies to protect sensitive and personal data for research. After completing the course, the interview questions and protocol were prepared and approved by UTEP IRB. The interview questions are divided into four parts, from A to D. Part A contained general questions about travelling from Ciudad Juarez to El Paso. Part B focused on the most recent trip the participant has made. Parts C and D consisted of questions focused on overall experience and suggestions.

The second method of the data collection was observation using tools such as cameras or public live reports. Firstly, the data published by CBP on average waiting times were collected. Secondly, manual observation of the live camera records of the PDN bridge was done. Before the explanation of actual data collection, a description of the public data is provided.

The CBP publishes to the public the real-time hourly data of average waiting time when crossing the PDN POE in the northbound direction. This real-time data is superimposed with the average trend that is calculated from historical data for a particular day in a particular month from the previous year [9]. The data for PDN POE are accessible online at the CBP website as well as in a mobile application called CBP Border Wait Times. The data are presented in graphs and tables at hourly intervals from 12:00 a.m. to 11:00 p.m. [9] Another possible source of data is the Bureau of Transportation Statistics (BTS). The BTS publishes monthly and annual entry data for all the POEs combined in the entire El Paso-Ciudad Juarez region. [24]. The BTS data do not have the necessary time, mode and geographical resolution and therefore is not useful for the scope of this thesis.

The CBP website provides the number of opened inspection booths in each hour. The real-time data of number of opened inspection booths have been collected from the CBP website analogous to average pedestrian volume data [9].

3.2.1 Interview

For this thesis, only one person who crosses by foot has been interviewed. This is because the mount of persons who crossed on foot during the pandemic was lower than expected. Because of the insufficient sample size, the results were not suitable for evaluation of the simulation model. However, the interviewed person provided details of the inspection process that served as a valuable resource for the "agent behavior" part of this thesis. This interview took place on Thursday December 9, 2021 in Computer and Science Building at UTEP. The identified answers are transcribed as follows:

Part A:

The subject crosses daily on foot from Ciudad Juarez to El Paso. The purpose of the trips is to study at UTEP. Most of the trips used the PDN POE. The subject used this POE because it has SENTRI lane (northbound) and has the fastest crossing time. Additionally, it is the closest POE to the trip destination in El Paso. For traveling from home to the south side of the PDN bridge in Ciudad Juarez and then from the POE in El Paso to UTEP, the subject uses public bus as the mode of transportation. The average trip time from home in Ciudad Juarez to UTEP is two hours.

Part B:

The recent trip was on Thursday December 9, 2021 during the morning peak. The subject arrived at the PDN POE at about 8:00 a.m. The subject used the SENTRI lane and thus did not have to wait in the queue. The subject observed that the length of queue of the general lane had more than 100 persons. In the inspection area, four or five general inspection booths were opened. The subject used the SENTRI lane and it took only one or two minutes to reach the CBP officer in the booth. The subject estimated that the waiting time at the general lane would take approximately two hours. The subject presented the SENTRI card, Mexican passport book and U.S. visa (Student F-1 Visa; I-20) to the CBP officer at the inspection booth. The security check of the documents took about two to three minutes. The subject commented that at the general lane, it may take up to five minutes at the inspection booth to check all the required documents.

Part C and D:

The subject has an experience with declaring food without paying an import tax and alcohol with payment of import tax. The subject described the process as smooth and relatively quick. The subject also has an experience with the secondary inspection due to an issue with a travel document. The subject shared the experience as additional check of the required documents in the secondary inspection area. This secondary inspection is necessary because the CBP officers are suspicious, or they want to be sure about the validity of the document. The secondary inspection took about 10 minutes and the subject said it may take up to 20 minutes in average. In Part D, the subject shared ideas how the border crossing may be improved. The subject thinks that more CBP officers should be at the bridge. This could improve the awareness about the situation at the bridge and accelerate the process of crossing.

Based on the interview and the author's own experience when crossing the PDN POE by foot, the average waiting times on weekdays on the PDN POE have been estimated. These values are listed in Table 3.1.

Table 3.1 – Waiting times from structured interview.

Area	Waiting Time (minutes)			
	Peak hours (5:00 a.m. – 9:00 a.m. and 3:00 p.m. – 5:30 p.m.)		Off-peak hours (the rest to peak hours)	
	General	SENTRI	General	SENTRI
Bridge lane	60-180	0-5	20-30	0-3
Lane	5-30	0-5	0-10	0-3
Primary Inspection	3-5	0-2	3-5	0-2
Secondary Inspection	10-20			

These numerical data retrieved from the interview will not be used as the actual model inputs.

3.2.2 Observation

Data collection for average waiting times at every hour has been done based on the information posted at the CBP website [9]. The data has been collected for one week for both the general and Ready lane from January 10, 2022 to January 16, 2022.

After reviewing the collected data, it was found that the average waiting times of the Ready lane did not differ from the general lane, a decision was made to use only the data for the general lane for both.

The collected average waiting times are shown in the following table (Table 3.2). The first column represents the hour of the day, and the next seven following columns represent the average waiting time on the seven days of the week. The website does not provide the period of the historical data range or how these values has been derived [9].

Table 3.2 – Average Waiting Time in northbound general lanes at Paso Del Norte Port of Entry from 10th to 16th of January 2022.

Average waiting time (minutes)							
TIME	MON	TUE	WED	THUR	FRI	SAT	SUN
	01/10/2022	01/11/2022	01/12/2022	01/13/2022	01/14/2022	01/15/2022	01/16/2022
12:00 a.m.	1 (1)	1 (1)	0 (1)	1 (1)	1 (1)	1 (1)	1 (1)
1:00 a.m.	0 (2)	1 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
2:00 a.m.	0 (1)	1 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
3:00 a.m.	0 (1)	1 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
4:00 a.m.	0 (1)	1 (2)	0 (1)	0 (2)	5 (3)	0 (1)	0 (1)
5:00 a.m.	15 (4)	2 (8)	20 (6)	25 (6)	25 (6)	0 (2)	0 (2)
6:00 a.m.	15 (11)	12 (14)	35 (8)	45 (13)	45 (11)	0 (3)	0 (3)
7:00 a.m.	15 (7)	30 (9)	40 (4)	45 (10)	45 (8)	0 (3)	0 (1)
8:00 a.m.	2 (6)	40 (23)	30 (13)	40 (13)	20 (10)	2 (3)	4 (2)
9:00 a.m.	5 (18)	35 (12)	15 (10)	35 (6)	20 (5)	1 (3)	2 (2)
10:00 a.m.	1 (14)	36 (2)	2 (2)	30 (7)	20 (5)	5 (6)	3 (3)
11:00 a.m.	5 (11)	25 (9)	7 (8)	30 (6)	15 (8)	7 (9)	1 (6)
12:00 p.m.	10 (8)	1 (3)	5 (7)	25 (4)	8 (14)	5 (11)	5 (6)
1:00 p.m.	10 (18)	2 (7)	3 (6)	25 (4)	40 (12)	7 (17)	7 (17)
2:00 p.m.	25 (6)	2 (6)	16 (11)	28 (7)	38 (9)	25 (13)	12 (9)
3:00 p.m.	35 (8)	25 (7)	4 (11)	30 (7)	50 (8)	35 (10)	15 (5)
4:00 p.m.	42 (19)	10 (3)	5 (10)	24 (6)	25 (9)	37 (14)	10 (11)
5:00 p.m.	45 (12)	5 (1)	1 (14)	1 (3)	1 (7)	45 (14)	1 (13)
6:00 p.m.	45 (7)	3 (1)	5 (13)	1 (1)	1 (4)	10 (7)	1 (11)
7:00 p.m.	1 (3)	1 (1)	1 (9)	3 (1)	1 (4)	1 (6)	1 (6)
8:00 p.m.	1 (3)	1 (1)	1 (1)	1 (1)	1 (2)	1 (1)	1 (5)
9:00 p.m.	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
10:00 p.m.	1 (2)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
11:00 p.m.	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)

For better visualization, the collected data have been plotted (Figure 3.3).

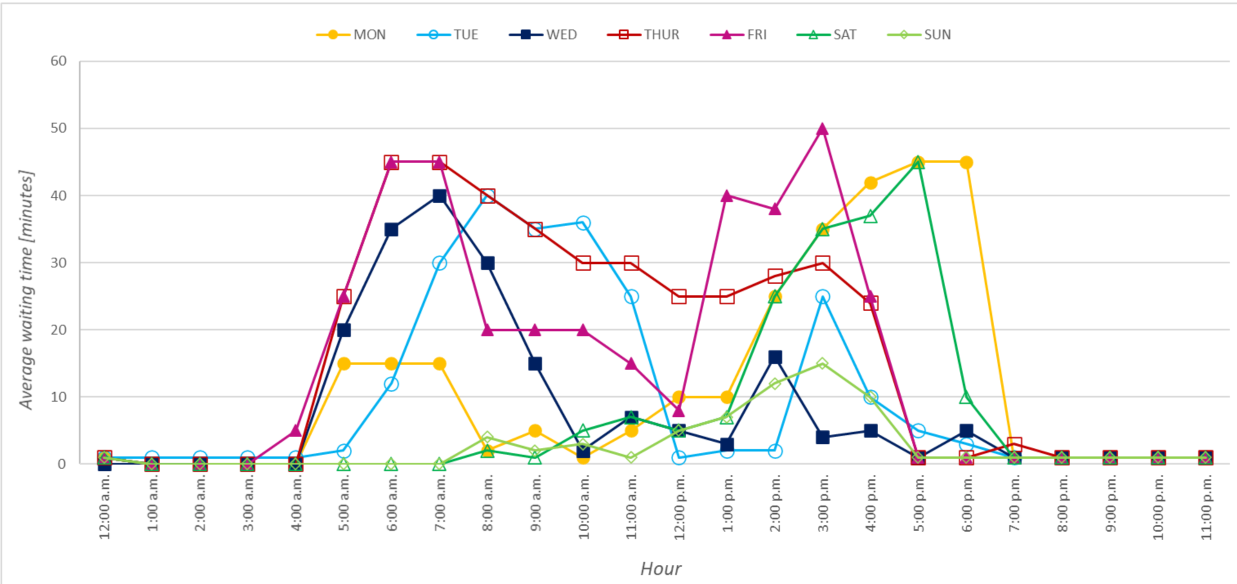

Figure 3.3 – Average waiting time in northbound general lane at Paso Del Norte Port of Entry from 10th to 16th of January 2022.

Additionally, the number of opened inspection booths has been collected. This data consists of values at every hour during a day. Again, the data has been collected for one week from January 10, 2022 to January 16, 2022. The collected numbers of opened inspection booths are shown in the following table (Table 3.3) [9].

Table 3.3 – Number of opened northbound inspection booths at Paso Del Norte Port of Entry from 10th to 16th of January 2022.

TIME	MON	TUE	WED	THUR	FRI	SAT	SUN
	01/10/2022	01/11/2022	01/12/2022	01/13/2022	01/14/2022	01/15/2022	01/16/2022
12:00 a.m.	2	2	2	2	2	2	2
1:00 a.m.	2	2	2	2	2	2	2
2:00 a.m.	2	2	2	2	2	2	2
3:00 a.m.	2	2	2	2	2	2	2
4:00 a.m.	2	2	2	2	2	2	2
5:00 a.m.	2	2	8	2	2	2	2
6:00 a.m.	8	2	8	9	8	6	6
7:00 a.m.	8	2	14	9	8	6	6
8:00 a.m.	8	7	14	8	7	4	6
9:00 a.m.	6	7	7	8	8	4	6
10:00 a.m.	5	7	7	8	6	5	6
11:00 a.m.	6	7	7	8	6	6	6
12:00 p.m.	8	7	8	8	6	6	6
1:00 p.m.	8	7	8	8	6	6	8
2:00 p.m.	8	4	8	8	5	10	10
3:00 p.m.	8	4	5	7	5	10	10
4:00 p.m.	6	6	5	7	5	8	10
5:00 p.m.	6	6	5	7	5	6	10
6:00 p.m.	4	6	5	4	6	8	8
7:00 p.m.	4	4	5	4	5	6	6
8:00 p.m.	4	4	5	4	4	4	4
9:00 p.m.	2	4	2	4	2	2	2
10:00 p.m.	2	4	2	4	2	2	2
11:00 p.m.	2	4	2	4	2	2	2

After data collection from the CBP website, the next set of data was the volume of pedestrian. This data collection was made possible by the live images of two cameras at the PDN

POE [24]. These cameras have been installed by the CBP and the live images are available to the public. The first one is placed approximately 73 meters upstream of the entrance to the inspection area and the second camera is located about 40 meters upstream of the inspection area. The method of observation was as follows. For each hour during the day, one 15-minutes slot has been selected and during this time period, the volume of pedestrian was counted. This value was scaled to hourly volume. The data collection has been done for one week to cover business days as well as weekend days. This data collection has been done in the same week as data collection for average waiting times, i.e., from January 10, 2022 to January 16, 2022.

The observed pedestrian volumes are presented in Table 3.4 [24]. The bold font represented the existence of a queue and italic font a smooth walk. The regular font is used for partial queue formation during the data collection.

Because Monday, January 16th, 2022 was the Martin Luther King Jr Day [25], a public holiday in the U.S., additional data collection has been done on one selected Monday February 16th, 2022. This data is displayed in Table 3.5 and is used instead of data in second column in Table 3.4. Font labels have the same reasoning as in Table 3.4.

Table 3.4 – Average hourly pedestrian volume in northbound general lanes at Paso Del Norte Port of Entry from 10th to 16th of January 2022 (part 1).

Average hourly pedestrian volume [persons]							
TIME	MON	TUE	WED	THUR	FRI	SAT	SUN
	01/10/2022	01/11/2022	01/12/2022	01/13/2022	01/14/2022	01/15/2022	01/16/2022
12:00 a.m.	*20*	*24*	*12*	*8*	*40*	*32*	*36*
1:00 a.m.	*8*	*8*	*12*	*20*	*4*	*16*	*32*
2:00 a.m.	*4*	*16*	*16*	*24*	*24*	*40*	*40*
3:00 a.m.	*216*	*188*	*24*	*20*	*172*	*24*	*32*
4:00 a.m.	**396**	**312**	**362**	**304**	*488*	*88*	*44*
5:00 a.m.	**512**	**700**	**426**	**352**	*652*	*66*	*52*
6:00 a.m.	**552**	**796**	**522**	**532**	*744*	*96*	*64*
7:00 a.m.	**416**	*306*	*360*	**556**	*600*	*376*	*128*
8:00 a.m.	*516*	**294**	*288*	**332**	570	*136*	*165*
9:00 a.m.	528	**312**	*392*	**472**	474	*624*	*270*
10:00 a.m.	*396*	**302**	**432**	**260**	*288*	*376*	*336*
11:00 a.m.	**432**	284	300	**312**	*258*	*444*	*252*
12:00 p.m.	**426**	214	248	**228**	**200**	582	*366*
1:00 p.m.	**432**	246	**208**	**348**	**372**	570	**245**
2:00 p.m.	**670**	280	272	*204*	**330**	**484**	**588**
3:00 p.m.	**420**	**302**	256	*820*	**624**	**320**	**552**
4:00 p.m.	**528**	**328**	236	*348*	**648**	**219**	*276*
5:00 p.m.	**405**	**296**	308	*196*	*276*	**448**	*348*
6:00 p.m.	468	*198*	*160*	*204*	*186*	*306*	*270*
7:00 p.m.	*300*	*122*	*68*	*102*	*138*	*162*	*192*
8:00 p.m.	*186*	*102*	*104*	*108*	*100*	*132*	*210*
9:00 p.m.	*168*	*68*	*40*	*72*	*32*	*60*	*78*
10:00 p.m.	*24*	*24*	*36*	*16*	*36*	*66*	*54*
11:00 p.m.	*40*	*24*	*30*	*12*	*16*	*48*	*42*

Table 3.5 – Average hourly pedestrian volume in northbound general lanes at Paso Del Norte Port of Entry on 16th of February 2022 (part 2).

Average hourly pedestrian volume [persons]	
TIME	MON 02/16/2022
12:00 a.m.	*12*
1:00 a.m.	*12*
2:00 a.m.	*16*
3:00 a.m.	*112*
4:00 a.m.	380
5:00 a.m.	**344**
6:00 a.m.	**972**
7:00 a.m.	**360**
8:00 a.m.	**355**
9:00 a.m.	*432*
10:00 a.m.	*312*
11:00 a.m.	546
12:00 p.m.	528
1:00 p.m.	*312*
2:00 p.m.	*204*
3:00 p.m.	*324*
4:00 p.m.	*156*
5:00 p.m.	*156*
6:00 p.m.	*150*
7:00 p.m.	*108*
8:00 p.m.	*102*
9:00 p.m.	*108*
10:00 p.m.	*48*
11:00 p.m.	*24*

For better illustration, the pedestrian volumes are converted into a chart below (Figure 3.4). As can be seen on the chart, the morning peak hours started at around 4:00 a.m. during weekdays and lasted until about 9:00 a.m. During weekends, the morning peak hours are not that obvious, especially on Sundays. On Saturdays, the volume was usually higher for the period from about 9:00 a.m. until 3:00 p.m. The highest peak happened on Thursday which is generally considered the busiest day of the week. The afternoon peak hours started around 3:00 p.m. and lasted until around 5:00 p.m. or 5:30 p.m.

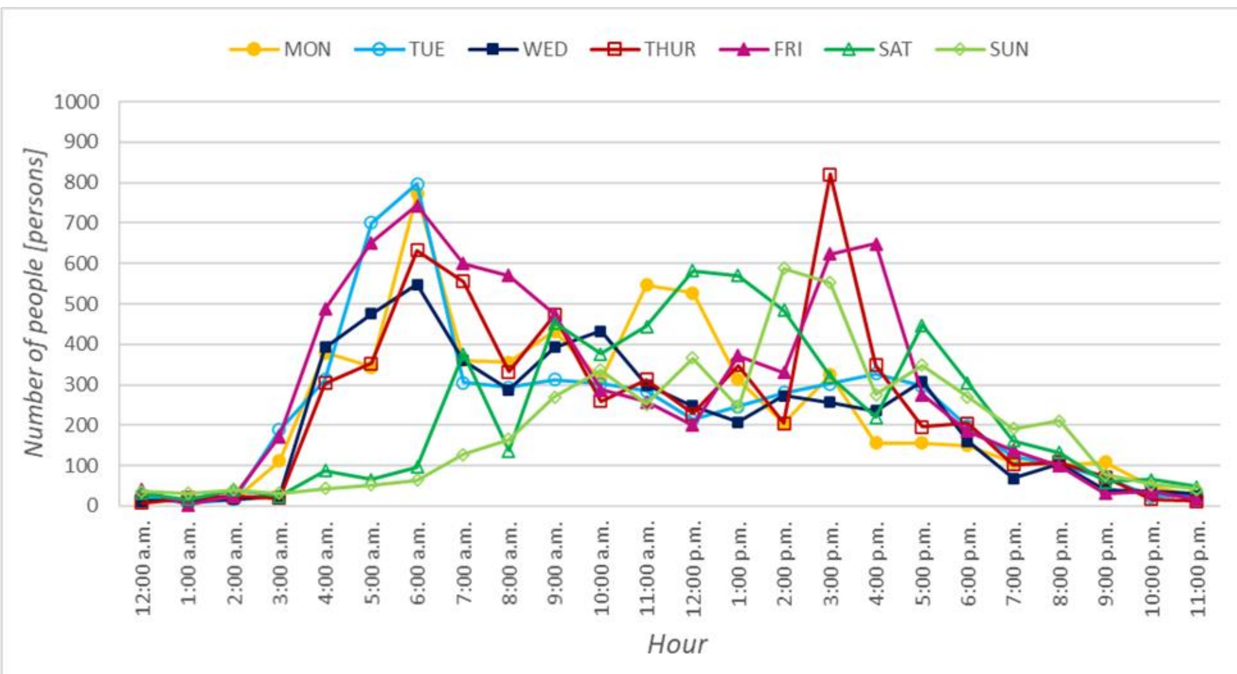

Figure 3.4 – Average hourly pedestrian volume in northbound Paso Del Norte Port of Entry from 10^{th} to 16^{th} of January 2022.

3.3 Simulation Model

After data collection, the simulation model was created in the AnyLogic. The model focuses on pedestrian flow in the inspection area with emphasis on the queues. The objective of the simulation was to estimate the average waiting time in a queue and use that to analyze the bottleneck of the northbound border crossing process on foot.

The model consists of the activities that happen in the inspection area where primary and secondary inspections are held.

The inspection area consists of five lanes. The first lane is dedicated to the pedestrians who require special assistance. The second lane is for pedestrians with the SENTRI card. The next two lanes are general lanes. The fifth lane is dedicated to students. In total, there are fourteen inspection booths. There is one inspection booth for pedestrians who need special assistance, two inspection booths for pedestrians with the SENTRI card, two inspection booths for students. The remaining nine inspection booths serve for pedestrians queuing at the two general lanes. Next to the primary inspection area is a secondary inspection area with two lanes and four inspection booths. Ahead of the entry to the inspection area, the approach to the POE from the PDN bridge called the bridge lane is modeled.

Figure 3.5 shows the modelled environment of the inspection area. The very left lane is a Special Assistance lane. Next to that, there is a SENTRI lane, two serpentine lanes are for regular pedestrians which are called General lanes. And the very right lane is a Student lane. This area of the inspection building is the primary inspection area. There is also one more grey path displayed on the right side next to the Student lane which is only auxiliary path which pedestrians use for leaving the model. The small room on the right side of the model is the secondary inspection area.

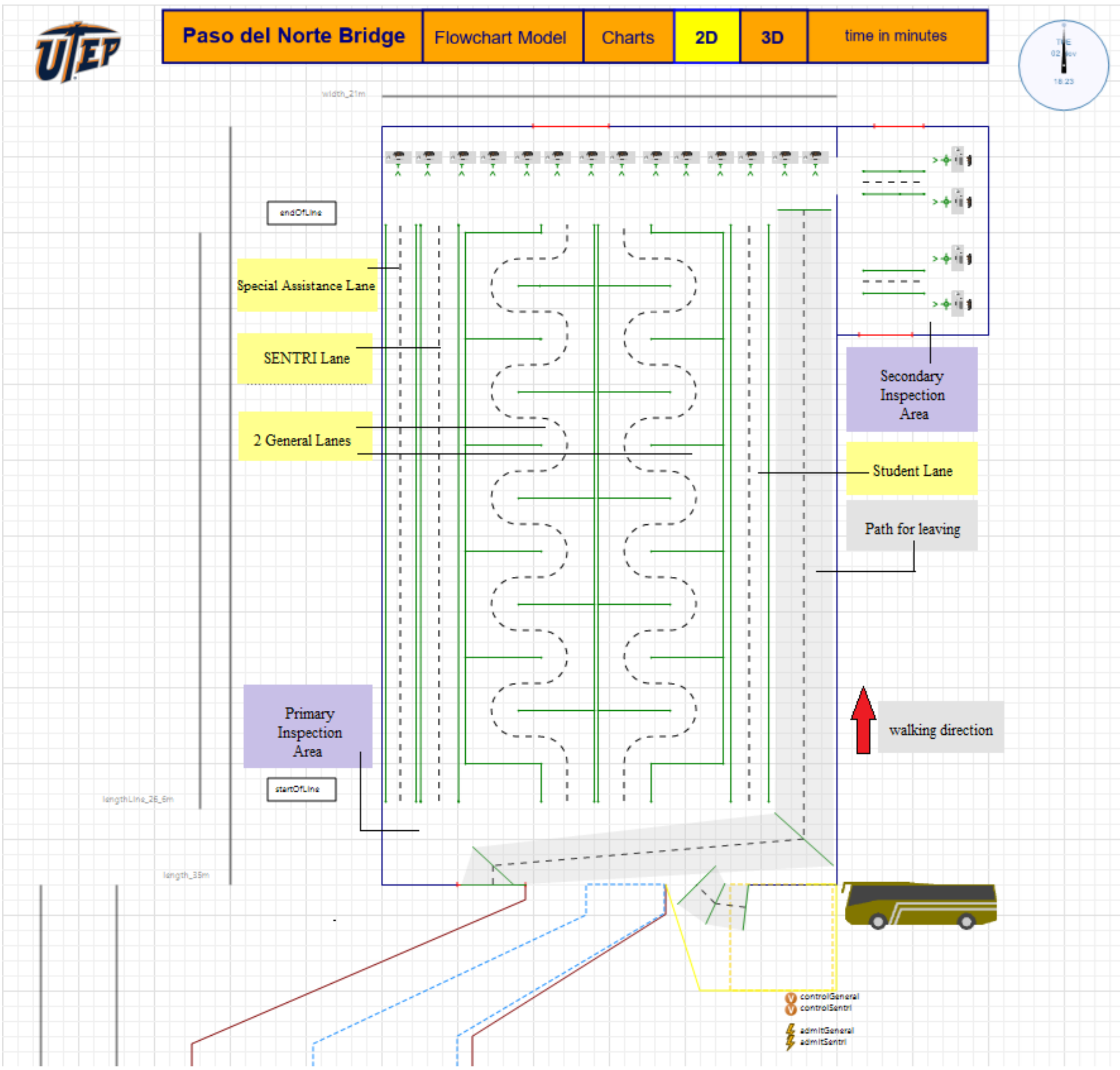

Figure 3.5 – Environment of the simulated inspection area in AnyLogic.

The units of the simulation were set to second. The arrival rate of pedestrians was in persons/hour at hourly intervals. The dimensions of the inspection area were measured from Open Street Map. The actual inspection area was about 70 m long and 21 m wide. After visiting the inspection area during a crossing trip, it has been decided not to include approximately the last 35 meters of the length of the building because it is not relevant, and this area is not studied. This inspection area features additional x-ray machines. All pedestrians that pass the inspection are supposed to place their belongings on the x-ray machine and then leave the building. For the purposes of this simulation modeling, this x-ray machines do not affect the desired outputs since it is placed downstream of the inspection booths. Therefore, the dimension of the inspection area in the model was set to 35 m by 21 m. The bridge lane length has been set to 77 meters. This length was chosen because the bridge lane was within the view of the two live cameras used in the data collection.

After creating the entire environment, a population of agents was created. This population of agents were all the pedestrians that crossed the PDN POE. The pedestrian arrival rate at the upstream end of the bridge lane was set to follow the data collected from the live cameras. Pedestrians may also arrive by bus. This arrival rate has been set to 5 to 10 passengers per hour, and again these values has been set based on the interview described earlier with one daily pedestrian who is also a bus user. The passengers from the bus skip the bridge lane and directly enter the inspection area and continue to the corresponding inspection booths.

The pedestrian walking speed followed a triangular distribution. The following figure (Figure 3.6.) shows the setting of the walking speed.

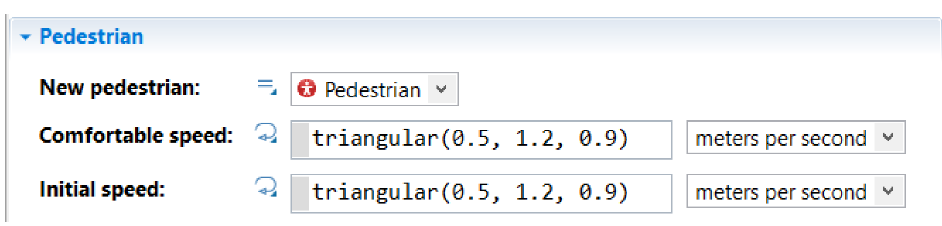

Figure 3.6 – Speed of pedestrians in simulation model.

Once a pedestrian enters the bridge lane, he/she needs to decide which lane to proceed. Four options were set using percentage rates. This distribution of pedestrian using the four lanes is shown in the Table 3.6. These values were set based on the interview and observation at the inspection area. The actual percentage of students is higher but many of the students used the SENTRI lane. A similar distribution was specified for bus passengers. The distribution of the bus passengers is shown in the Table 3.7.

Table 3.6 – Distribution of pedestrians in simulation model.

Type of pedestrian/lane	Group	Percentage [%]
Special assistance	1	2
SENTRI	2	23
General	3	67
Student	4	8

Table 3.7 – Distribution of pedestrians arrived by bus in simulation model.

Type of pedestrian/lane	Group	Percentage [%]
Special assistance	1	15
SENTRI	2	15
General	3	50
Student	4	20

Another parameter in the simulation that is connected to the pedestrians and their behavior is groups. These groups mostly represent families that are walking together. Groups are considered in the general, SENTRI and Special Assistance lanes. The group size in the general lanes has been set up to four members with lognormal distribution. In the special lane and the SENTRI lane, the maximum group size was two. No formation of group was allowed in the student lane.

The next general parameter for all the intended scenarios is the delays at the primary inspection booth. Different distributions were used for the four different types of pedestrians. Table 3.8 shows the delay times that were set with the use of the triangular distribution based on the observation and supplemented by experience during a crossing trip.

Table 3.8 – Delay time at inspection booths in simulation model.

Delay time at the inspection booth			
Type of pedestrian/lane	Min value (min)	Mode value (min)	Max value (min)
Special assistance	1.5	2.0	3.0
SENTRI	0.5	0.9	1.5
General	1.0	2.0	3.0
Student	1.0	1.5	2.5

The Table 3.9 shows the percentage of pedestrians who were sent from the primary inspection booths to the secondary inspection and the delay time at the secondary inspection booth. The pedestrians at the special assistance lane were not sent to undergo the secondary inspection.

Table 3.9 – Parameters of secondary inspection in simulation model.

Type of pedestrian/lane	Percentage [%]			Delay time at inspection booth		
	Pass the primary inspection	Sent to the secondary inspection	Denied entering the U.S. after the primary inspection	Min value [min]	Mode value [min]	Max value [min]
SENTRI	97.0	2.5	0.5	5.0	7.0	15.0
General	93.0	5.0	2			
Student	95.0	4.5	0.5			

The last parameter is the percentage of pedestrians that are denied entering the U.S. This percentage is different at each stage of the process. As can be seen in the table above in the second and the third column, the sum of the percentage does not respond to 100 %. For example, pedestrians from SENTRI lane pass the primary inspection in 97 % and 2.5 % is sent to the secondary inspection. The remaining 0.5 % is denied entering the U.S. already at the primary inspection. The same percentage was set for students. For pedestrians in the general lanes, the value was set to 2 %. This means that 2 % of pedestrians using the general lanes are declined entering the U.S. already after the primary inspection. The Table 3.10 shows the percentage distribution for the secondary inspection.

Table 3.10 – Distribution for secondary inspection in simulation model.

Type of pedestrian/lane	Pass the secondary inspection [%]	The entry denied [%]
SENTRI	95.0	5.0
General	90.0	10.0
Student	95.0	5.0

All the parameters mentioned above are included in the entire logic model of the model itself. This logic model is a kind of a flowchart that represents how agents (pedestrians) are moving though the environment. It begins with a source where pedestrians are generated. Also, there is a source for bus passengers. These blocks actually cause pedestrian figures to appear on screen when the simulation is running. Then, the pedestrians proceed to the bridge lane and at the end of this part, they enter first decision point in the flowchart. The simulation model decides if a pedestrian is supposed to use SENTRI, General, Student or Special Assistance lane. If the assigned lane in the inspection building is full (the queue has reached the maximum length), the model keeps pedestrian to wait in the bridge lane. This ensures that the inspection area is not overcrowded, and the pedestrians of multiple types form a queue on the bridge lane, while waiting to be admitted into the inspection area. Once the pedestrians enter the inspection area and join the assigned lane, they simply proceed to the inspection booth to be served. At this point, there is again a decision node in the logic model. This node makes the primary inspection decision: if the pedestrian can be admitted to the U.S. or the secondary inspection is required. The rest of the flowchart is ensuring that all the pedestrians leave the inspection area and enter the U.S., return to Mexico, or detained.

The very last block of the flowchart is sink which assures that the agents (pedestrians) disappear from the model. Moreover, with this block, all data connected to each particular pedestrian is collected and logged into database. The described logic model is displayed below on the Figure 3.7.

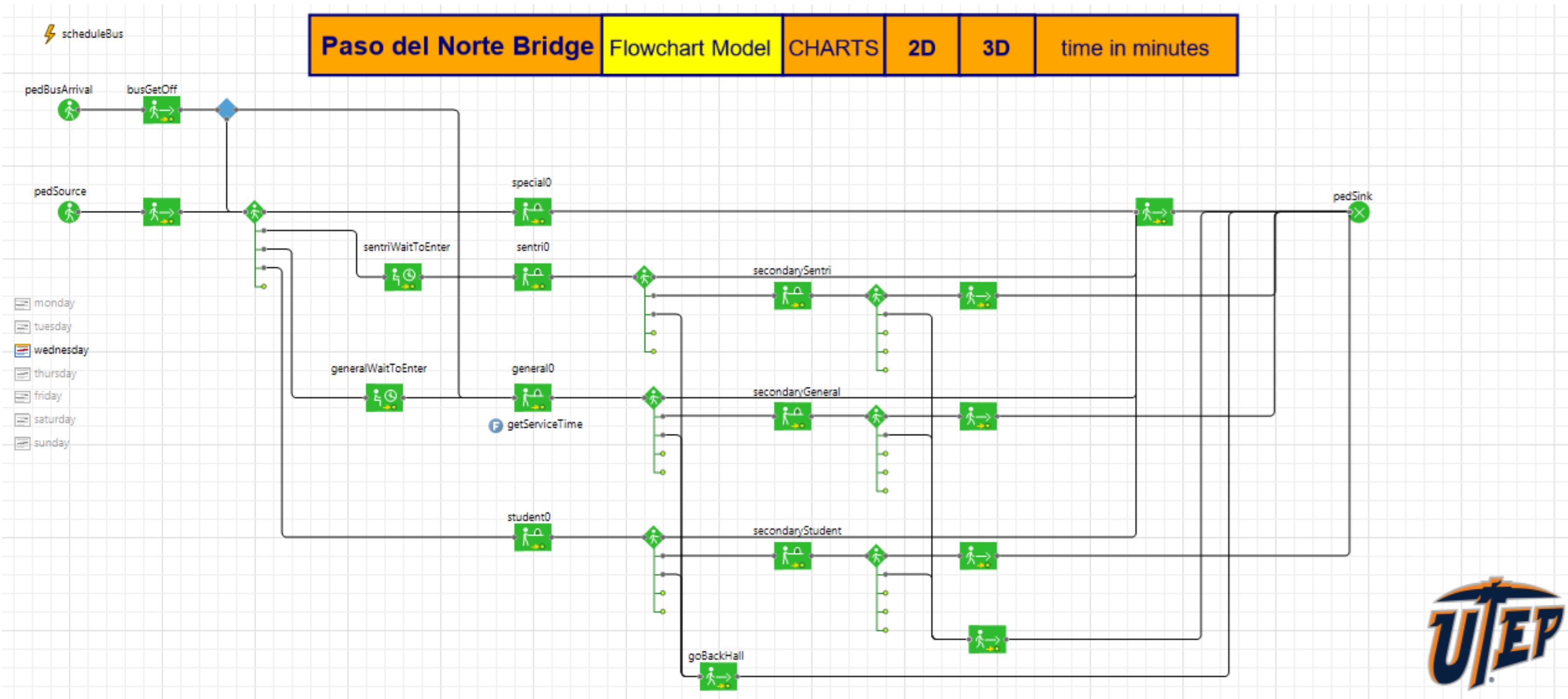

Figure 3.7 – Logic model coded in AnyLogic.

All these values are assumed based on either the information from interview or the observation at the PDN bridge during several visits for the research purposes.

The following outcomes of the simulation were recorded in the output files and analyzed:

- Average waiting time spent in a certain lane in the inspection area;
- Number of pedestrians in the lane during the day; and
- Number of open inspection booths during the day.

3.4 EXPERIMENTS

Three scenarios were simulated. Detailed descriptions of the scenarios and parameters are provided in the next subchapters. Each scenario followed the pedestrian arrival rates for Wednesday (January 12th, 2022) or Sunday (January 16th, 2022). For each scenario, simulations runs were made with 10 repetitions and the outputs (queue length, waiting time, number of open inspection booths) were averaged and analyzed.

Although the simulation model included Special Assistance lane, the number of pedestrians who needed special assistance was not significant and therefore the outputs from this group of pedestrians were not evaluated.

3.4.1 Scenario 1

Scenario 1 was called Maximum Number of Booths. The Maximum Number of Booths scenario operated with all the inspection booths opened for the entire day. This scenario gave the highest possible throughput. The expected outcome is the shortest waiting times according to the current infrastructure.

3.4.2 Scenario 2

Scenario 2 was called Observed Number of Booths. The Observed Number of Booths scenario reflected the situations on the days of the data collection. The outputs should be the closest to the collected data values reported in Section 3.2.2. The purpose of the Scenario 2 was to use the collected average waiting times from the CBP website to validate the waiting times produced by the simulation model. The simulated number of open inspection booths are listed in the Table 3.11.

Table 3.11 – Observed number of opened northbound inspection booths at Paso Del Norte Port of Entry on January 12th and 16th, 2022.

Wednesday (January 12th, 2022)		Sunday (January 16th, 2022)	
Hour	No. of booths	Hour	No. of booths
12:00 a.m.	2	12:00 a.m.	2
1:00 a.m.	2	1:00 a.m.	2
2:00 a.m.	2	2:00 a.m.	2
3:00 a.m.	2	3:00 a.m.	2
4:00 a.m.	7	4:00 a.m.	2
5:00 a.m.	7	5:00 a.m.	2
6:00 a.m.	7	6:00 a.m.	6
7:00 a.m.	9	7:00 a.m.	6
8:00 a.m.	9	8:00 a.m.	6
9:00 a.m.	7	9:00 a.m.	6
10:00 a.m.	7	10:00 a.m.	6
11:00 a.m.	7	11:00 a.m.	6
12:00 p.m.	7	12:00 p.m.	7
1:00 p.m.	7	1:00 p.m.	7
2:00 p.m.	7	2:00 p.m.	9
3:00 p.m.	7	3:00 p.m.	9
4:00 p.m.	5	4:00 p.m.	9
5:00 p.m.	5	5:00 p.m.	6
6:00 p.m.	5	6:00 p.m.	6
7:00 p.m.	5	7:00 p.m.	6
8:00 p.m.	5	8:00 p.m.	6
9:00 p.m.	5	9:00 p.m.	2
10:00 p.m.	2	10:00 p.m.	2
11:00 p.m.	2	11:00 p.m.	2

3.4.3 Scenario 3

Scenario 3 was called Dynamic Number of Booths. The Dynamic Number of Booths scenario allowed hourly dynamic variations of opened inspection booths (for the general lanes) based on the arriving pedestrian volume.

In Scenario 3, the opening and closing of inspection booths follows certain rules. The model counted the number of pedestrians queueing in the general lanes and every fifteen minutes it called for the opening of a new inspection booth if possible. It also reacted to the lower number of pedestrians in the queue and the model called for the closure of an inspection booth.

The flowchart of the logic is displayed below in Figure 3.8. The logic assumed that when the general lane has reached 70 % of its capacity, an inspection booth should be opened. In opposite case, when the lane occupancy dropped below 15 %, one inspection booth should be closed.

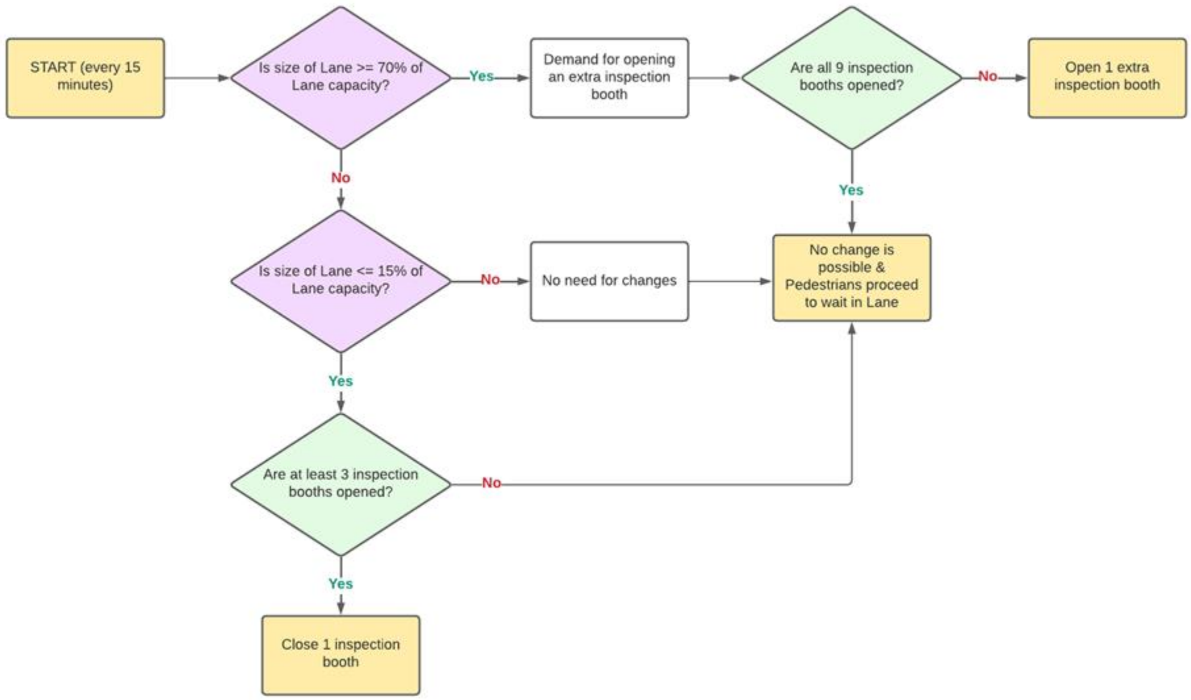

Figure 3.8 – Flowchart for opening and closing of inspection booths in Scenario 3.

Chapter 4: Simulations Outputs

This chapter provides an explanation of the obtained outputs from the AnyLogic simulations. This description serves for better understanding of discussions of the results in Chapter 5. The organizations of the output data are explained with the help of examples in this chapter. The full set of output data is attached in the Appendix.

Table 4.1 shows a summary of the data obtained from the AnyLogic simulation for one chosen scenario for one selected day, in this case Scenario 3 on Wednesday. This table presents the output data after data processing. The first column of the table shows the time of the day, hour by hour. The next three columns stand for the number of opened inspection booths distinguished by the type of lane. They are followed by three columns of the average number of the pedestrians waiting in the lane. The last three columns display the average waiting time in the lane. According to the model environment, these columns are separated for each type of the lane (General, SENTRI, Student).

Table 4.1 – Example of output table.

Time	No. of booths			Average queue length (persons)			Average waiting time (minutes)		
	General	SENTRI	Student	General	SENTRI	Student	General	SENTRI	Student
12:00 a.m.	2	2	2	1	1	1	0	0	0
1:00 a.m.	2	2	2	1	1	1	0	0	0
2:00 a.m.	2	2	2	1	1	1	0	0	0
3:00 a.m.	2	2	2	1	1	1	0	0	0
4:00 a.m.	2	2	2	93	2	1	20	0	0
5:00 a.m.	5	2	2	193	4	1	56	1	0
6:00 a.m.	8	2	2	173	8	1	47	3	0
7:00 a.m.	9	2	2	169	6	1	31	3	0
8:00 a.m.	9	2	2	169	2	1	31	0	0
9:00 a.m.	9	2	2	169	3	1	31	1	0
10:00 a.m.	9	2	2	168	4	1	31	1	0
11:00 a.m.	9	2	2	169	2	1	31	1	0
12:00 p.m.	9	2	2	171	2	1	31	0	0
1:00 p.m.	9	2	2	173	1	1	31	0	0
2:00 p.m.	9	2	2	125	2	1	28	0	0
3:00 p.m.	8	2	2	65	2	1	16	0	0
4:00 p.m.	4	2	2	51	1	1	13	0	0
5:00 p.m.	3	2	2	134	2	1	32	0	0
6:00 p.m.	6	2	2	157	2	1	50	0	0
7:00 p.m.	6	2	2	62	1	1	31	0	0
8:00 p.m.	3	2	2	14	1	1	10	0	0
9:00 p.m.	2	2	2	16	1	1	13	0	0
10:00 p.m.	2	2	2	6	1	1	5	0	0
11:00 p.m.	2	2	2	4	1	1	2	0	0

As mentioned earlier in Chapter 3, each prepared scenario was run twenty times in total, ten times for Wednesday and ten times for Sunday. AnyLogic allows creating a database where the required output "datasets" are logged with every repetition. During designing the model, this database file has been created and following datasets have been set to log into:

- Dataset of the number of the pedestrians in the SENTRI lane
- Dataset of the number of the pedestrians in the General lane
- Dataset of the number of the pedestrians in the Student lane
- Dataset of the waiting times of each pedestrian in the SENTRI lane

- Dataset of the waiting times of each pedestrian in the General lane
- Dataset of the waiting times of each pedestrian in the Student lane.

Additionally, for Scenario 3, one more dataset was logged into the database. This dataset retrieved the number of opened inspection booths based on the queue length in the general lanes.

All the datasets mentioned in the bullet points above were saved for the length of every simulation run, i.e., 24 hours. Since the model units are set to seconds, all the data were linked to time value in seconds. Anyhow, after running the simulation for 24 simulation hours, AnyLogic updates the database file with current data and this file needs to be saved. Otherwise all the data would be rewritten after successive simulation iteration. After running ten iterations, the main data processing was done. This part of data processing required several steps. Firstly, merging all the obtained data into one Excel file. This Excel file consists of six sheets, one per one dataset. The first three sheets include data for a queue length. The next three sheets are for waiting times data. In each of the sheets, several data processing steps have been done for acquiring average values either for the number of the pedestrians in the lane and the average waiting time in the lane. Then, all the found averages were added to the table presented in the Table 4.1 in columns Average queue length (persons) and Average waiting time (minutes). Every part is linked to an appropriate time format, so the outcomes are relevant in the time context. For example, when talking about average waiting time, it is the most convenient to convert the time stamps to minutes because the unit of minutes is commonly used in this case.

Chapter 5: Evaluation of Results

This chapter analyzes the outputs obtained from the AnyLogic simulations. The first part of the evaluation compared the number of opened inspection booths among the three scenarios. The second part compared the average waiting times collected from the CBP website and from Scenario 2. The third part compared the average waiting times from all the scenarios. The fourth part presented a comparison of the queue length among the three scenarios.

The evaluation of the last two sections is separated for the general lanes and the SENTRI lane. Additionally, there is a short analysis of one attribute that has been chosen for further description. This attribute is the median of the average waiting time in the general lane for both simulated days.

5.1 Number of Open Booths

The first attribute selected for comparison of the three simulated scenarios is the number of open inspection booths. The first analysis is for Wednesday and the second one is for Sunday as can be seen in Figure 5.1 and Figure 5.2. Scenario 2 followed the collected data from the CBP website and Scenario 3 followed the dynamic outputs obtained from the simulation. In Figure 5.1, the line for Scenario 3 shows that during morning peak, the POE responded by opening more inspection booths starting at 4:00 a.m. and by 8:00 a.m. all the inspection booths for the general lanes were opened. The number of open inspection booths remained at nine until 2:00 p.m. By 5:00 p.m. it was reduced to three inspection booths. The afternoon/evening peak started at about 5:00 p.m. and ended at about 8:00 p.m. During these afternoon/evening rush hours, the model did not open all the nine inspection booths but only six. Figure 5.2 shows that based on the collected data for Scenario 2, from 6:00 a.m. until 8:00 p.m. there are at least six inspection booths opened.

But based on the dynamic schedule of Scenario 3, it is obvious that the peak on Sunday started at about 11:00 a.m. and lasted until 7:00 p.m. The output data from Scenario 3 on Sunday showed that the number of the open inspection booths can be modified based on the queue length.

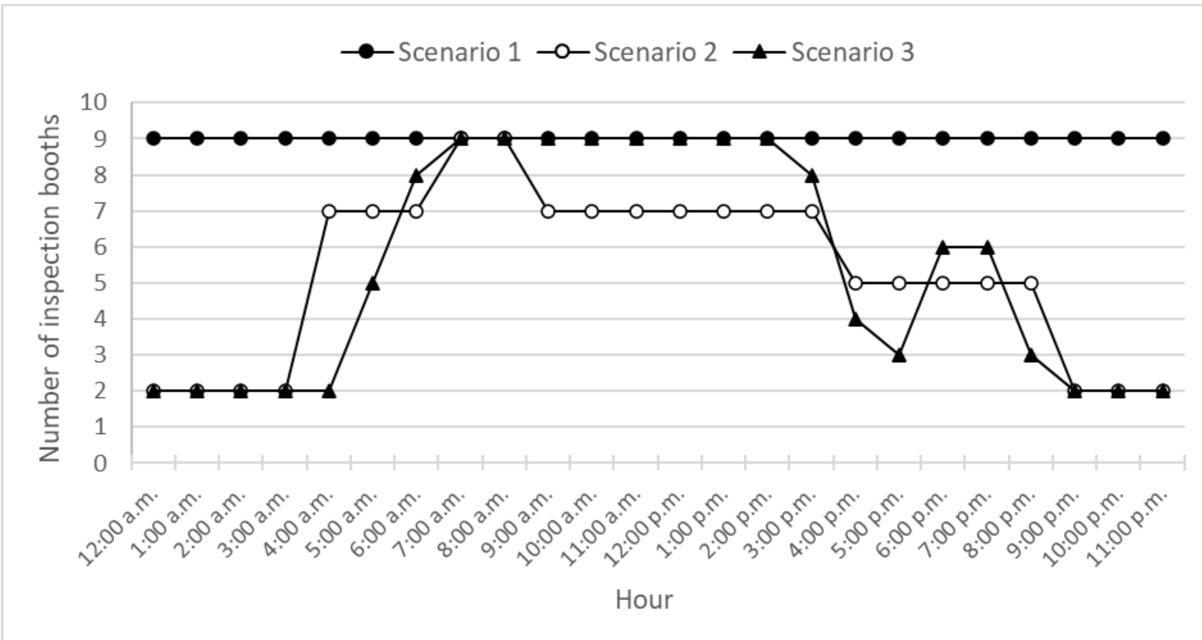

Figure 5.1 – Number of open inspection booths on Wednesday.

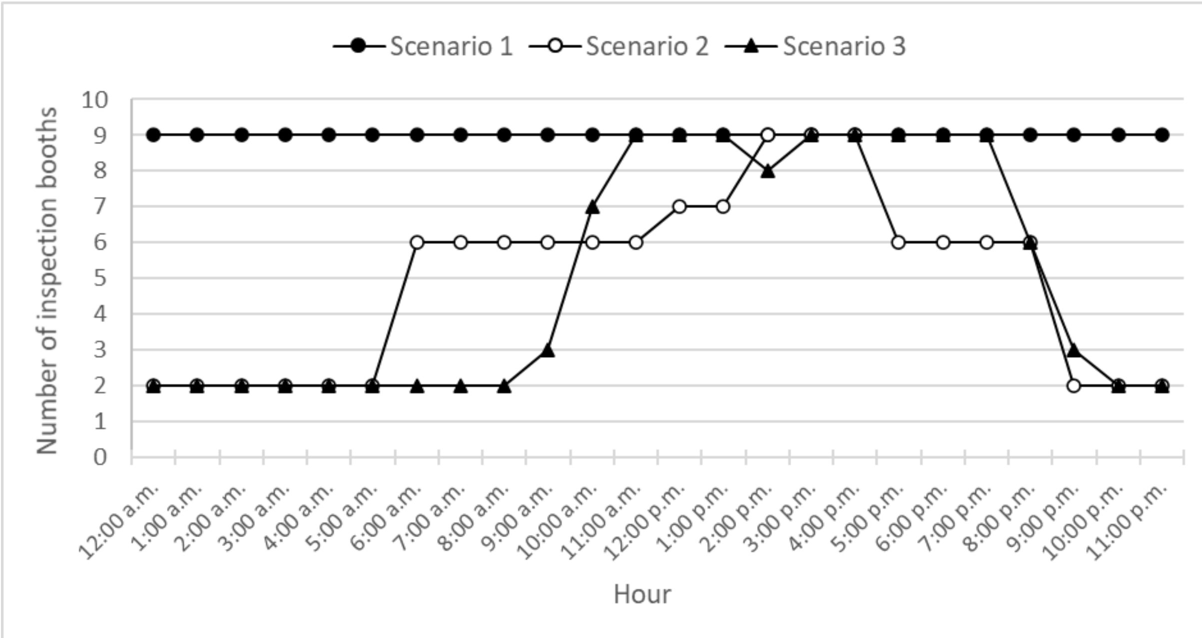

Figure 5.2 – Number of open inspection booths on Sunday.

5.2 Comparison of Simulated and Observed Waiting Times

The second attribute to compare is the waiting time in the general lanes. This analysis covers only Scenario 2 and evaluation of the collected waiting time data from the CBP website and simulation's outputs. Figure 5.3 and Figure 5.4 compared the observed average waiting time (from the CBP) and the obtained average waiting times (from simulations) on Wednesday and Sunday. As can be seen in Figure 5.3, the shape of the curves differs a lot in the afternoon. This diversity may be caused by several reasons. The first potential reason for the difference is the possible inaccuracy of the data at the CBP website. Another possible explanation is an inaccurate input data of pedestrian volume into the simulation.

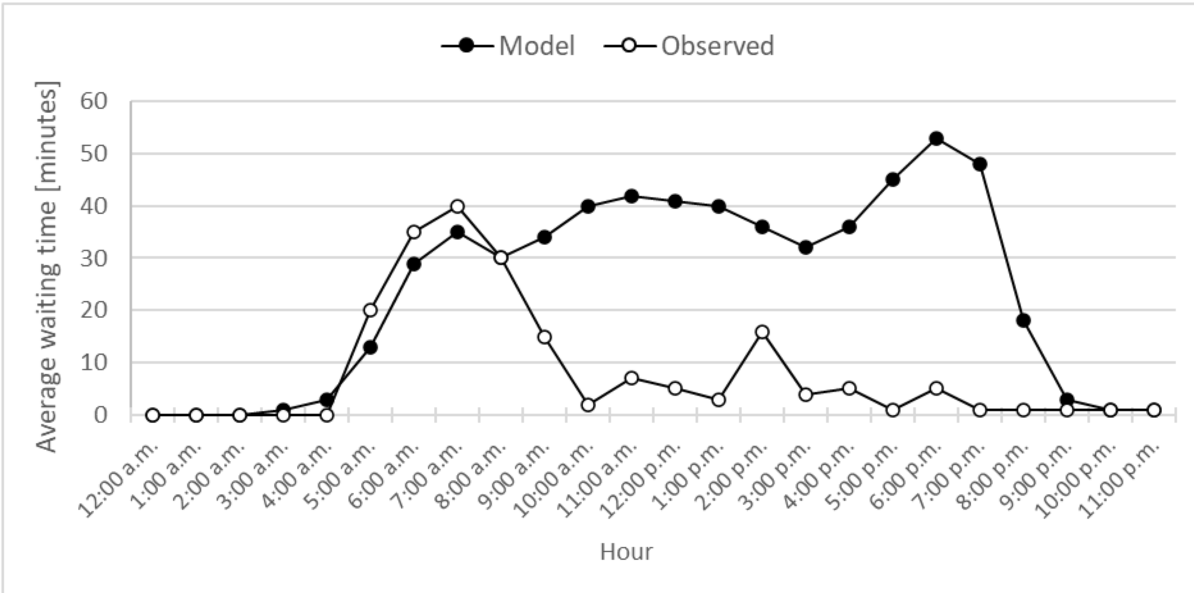

Figure 5.3 – Average waiting time for Scenario 2 on Wednesday.

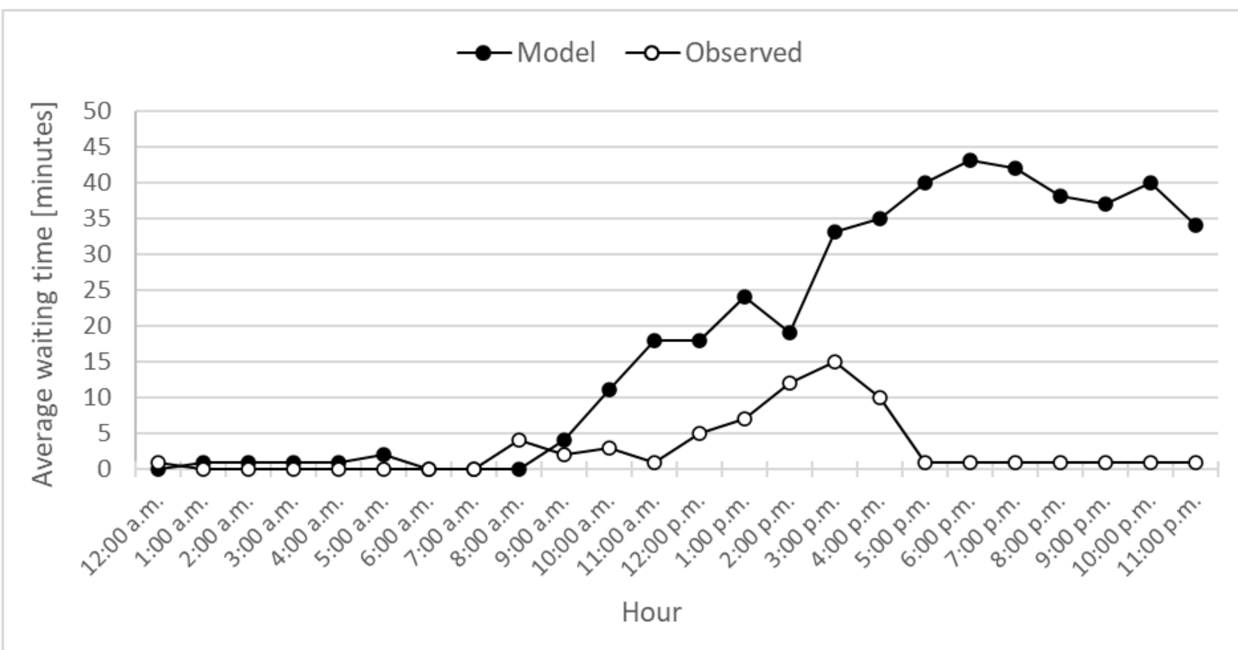

Figure 5.4 – Average waiting time for Scenario 2 on Sunday.

5.3 AVERAGE WAITING TIME

The next set of outputs compared was the average waiting time. The following analyses are provided for the general lanes and the SENTRI lane separately. The outputs from the Student lane were not considered in this evaluation because it did not show any valuable outcomes for comparison as the average waiting time was one minute maximum.

Figure 5.5 shows the average waiting time in the general lanes on Wednesday. As expected, Scenario 1 shows a lower average waiting time than the remaining two scenarios. Scenario 2 displays that the average waiting time during the morning peak is approximately 30 minutes and during the afternoon/evening peak it was higher, about 45 to 53 minutes. Scenario 3 did not show good results at 4:00 a.m. and 5:00 a.m. Unexpectedly, the average waiting time went up to 57 minutes at 5:00 a.m. which could be explained by delayed reaction of the opening more inspection booths. As can be seen on the Figure 5.1, the number of open inspection booths at 4:00 a.m. was only two and at 5:00 a.m. only five out of maximal nine. This high peak recorded from Scenario 3 at 5:00 a.m. could be modified in the model by shortening the interval when the model asks about the queue length comparing to the lane capacity. If the interval is shorter, then more inspection booths could be open earlier and the average waiting time might be lower.

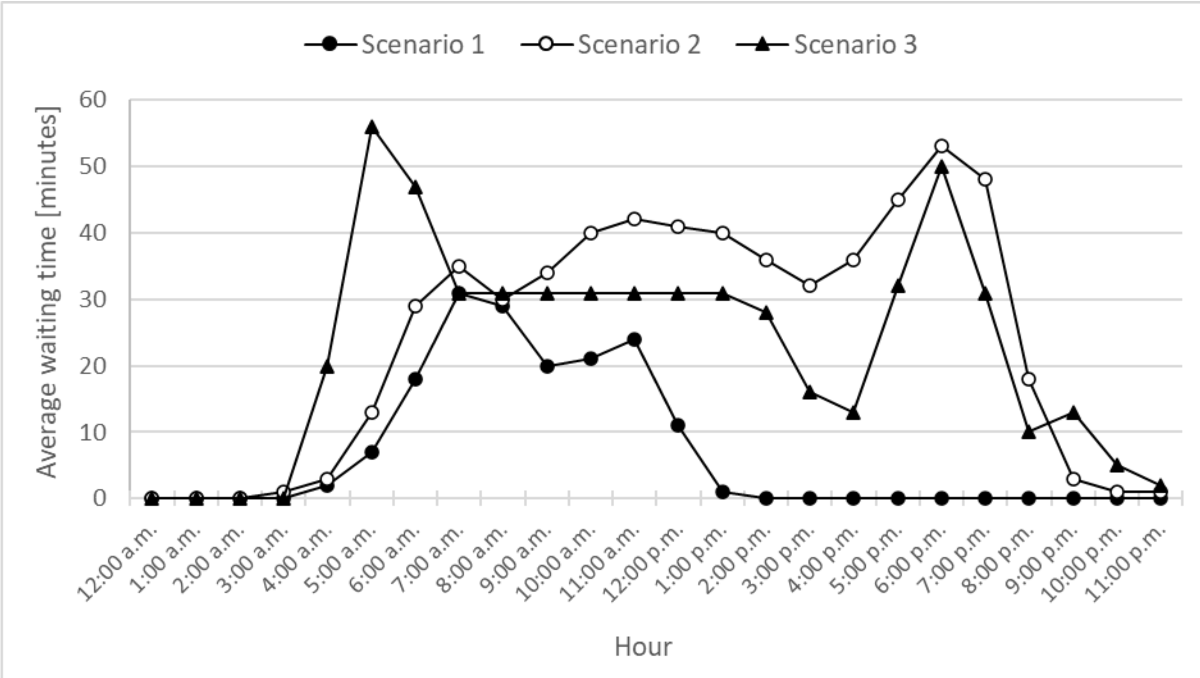

Figure 4.5 – Average waiting time in general lanes on Wednesday.

Figure 5.6 shows the average waiting time in the SENTRI lane on Sunday. This outcome has one unexpected result. The highest average waiting time in Scenario 2 (7 minutes at 3:00 p.m.) is lower than the highest average waiting time in Scenario 3 (9 minutes at 3:00 p.m.).

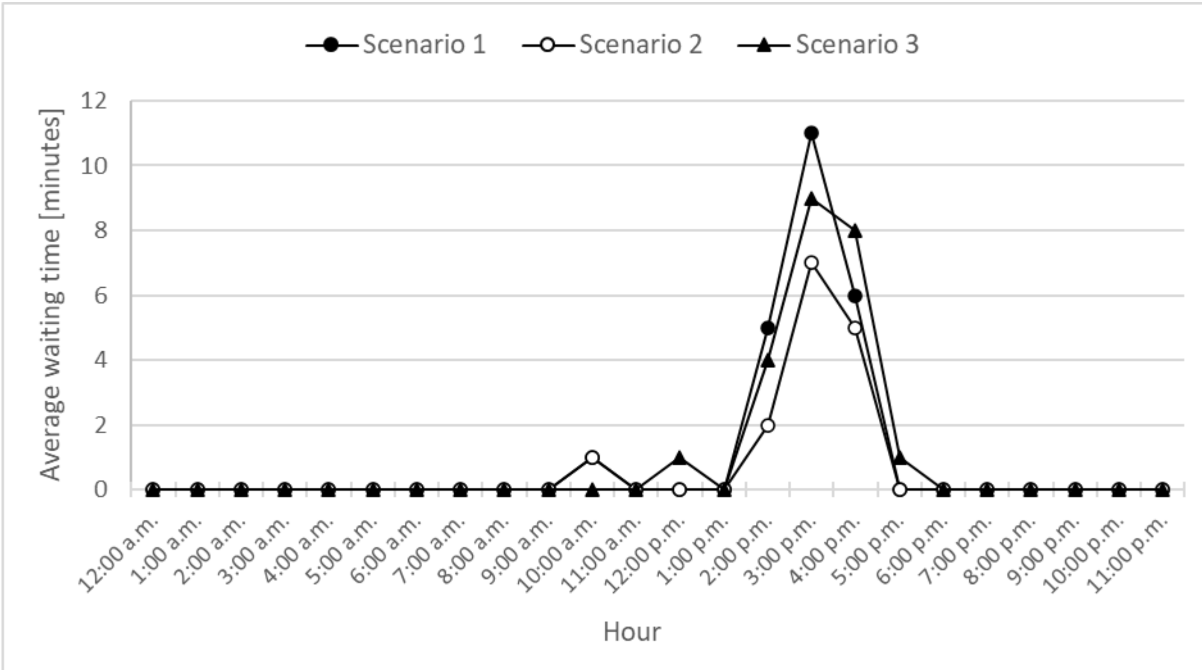

Figure 5.6 – Average waiting time in SENTRI lane on Sunday.

5.4 AVERAGE QUEUE LENGTH

The last set of outputs evaluated was a queue length. The queue length is the number of pedestrians waiting in a certain lane to be served at the inspection booth. The analysis of this outcome is separated by the general lane and the SENTRI lane. Figure 5.7 shows the changes in the number of pedestrians waiting in the general lane on Wednesday. Scenario 1 resulted in the lowest number of pedestrians in a queue for the entire day. Scenario 2 shows rather long queue since 6:00 a.m. for almost all day long until 6:00 p.m. with only a slight drop between 3:00 p.m. and 5:00 p.m. More evident contrast during the morning peak and the afternoon/evening peak can be seen from the results obtained from Scenario 3. Also, Scenario 3 results display the highest value at 5:00 a.m. (193 pedestrians in the two general lanes).

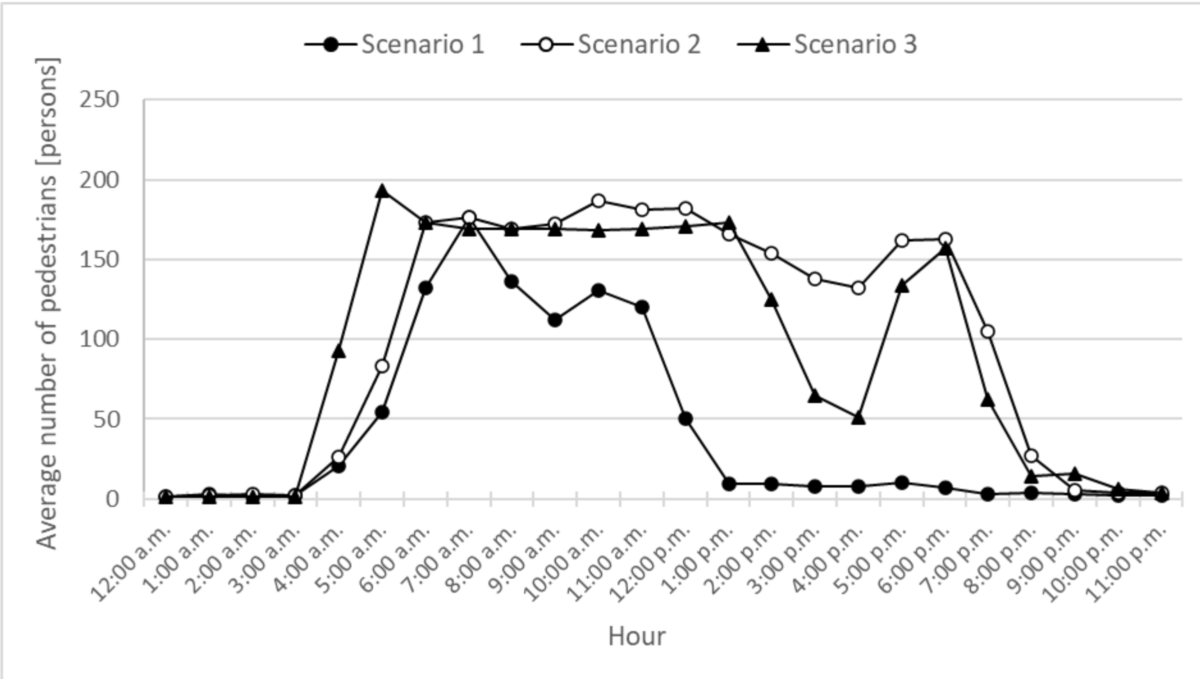

Figure 5.7 – Average number of pedestrians in general lanes on Wednesday.

The next analysis focuses on the results from the SENTRI lane on Wednesday. These results are presented in Figure 5.8. All three scenarios showed a very high morning peak approximately from 5:00 a.m. to 8:00 a.m. The longest queue in the SENTRI lane was recorded in Scenario 2 at 6:00 a.m. (11 pedestrians). Similarly, as the evaluation of results displayed on the Figure 5.5, this chart shows the need of multiple iterations of simulation because the inputs for the SENTRI lane (arriving pedestrian volume and number of open inspection booths) do not vary among the scenarios. Although the number of open inspection booths for the SENTRI lane remains the same, the arriving pedestrian volume can be slightly different because the AnyLogic model operates with percentage parameters and the actual amount of the arriving pedestrian fluctuates in a range set by the AnyLogic.

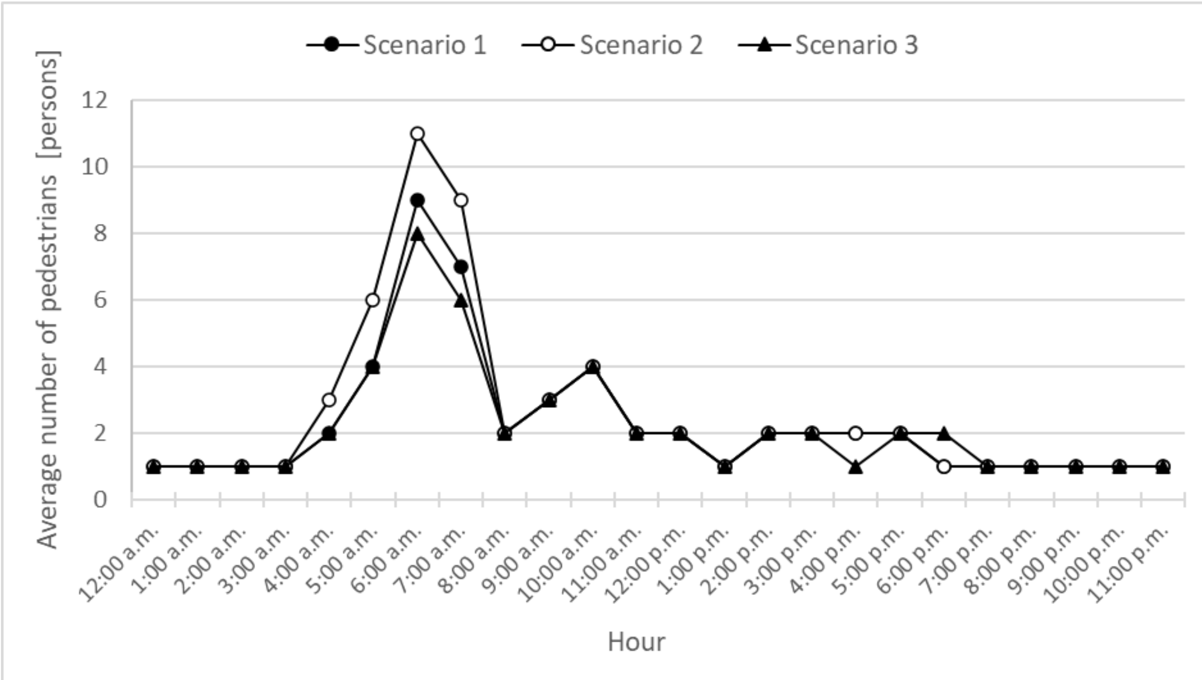

Figure 5.8 – Average number of pedestrians in SENTRI lane on Wednesday.

The average number of pedestrians in the general lanes on Sunday is shown in Figure 5.9. The Scenario 1 shows the shortest queue length among the three scenarios. Scenario 3 had a sharp rise in queue length at 7:00 a.m. indicating its slow response to the growth in queue length.

The results from Scenario 2 present a gradual increase since already 9:00 a.m. with the highest value of 193 pedestrians (3:00 p.m.) in the both general lanes. The afternoon/evening peak hours recorded in Scenario 2 shows a very slow decrease and the queue length is still pretty high. This corresponds with results presented on the Figure 5.4 where the average waiting times on Sunday from Scenario 2 are shown.

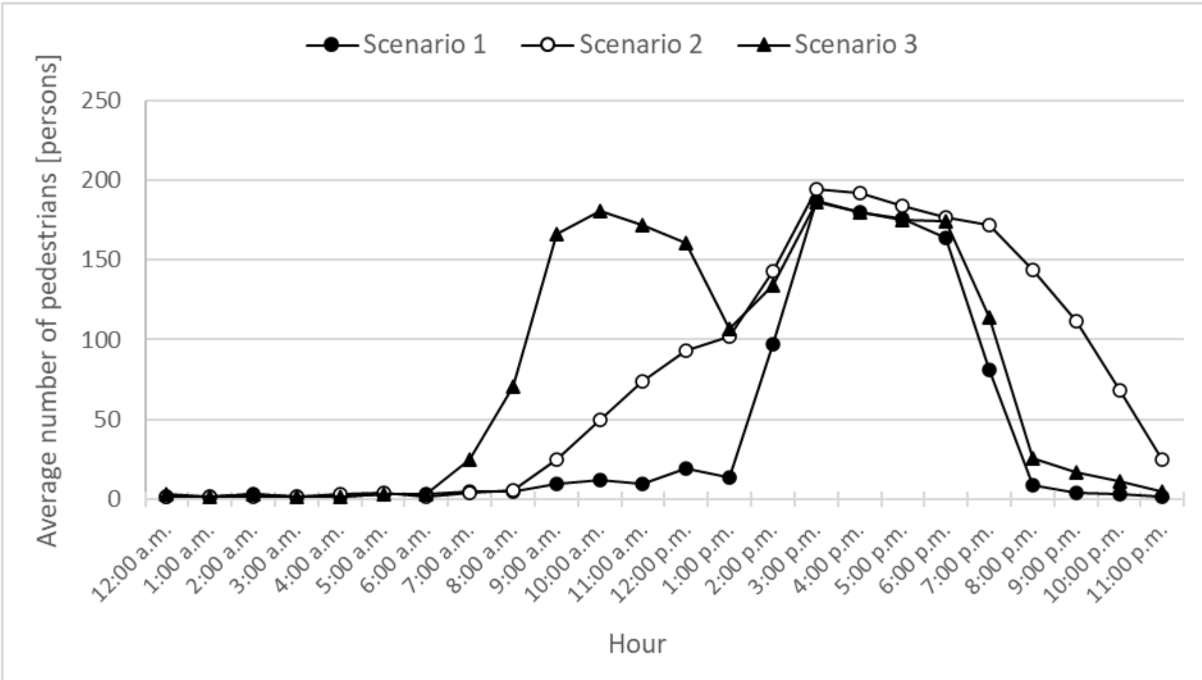

Figure 5.9 – Average number of pedestrians in general lanes on Sunday.

5.5 Median Waiting Time

The last attribute to analyze and describe is the median of the average waiting times. Figure 5.10 shows the medians of the average waiting time in the general lanes on both simulated days. The median of the average waiting time is the median value among the 24 hours. As can be seen, Scenario 1 feature with the lowest values for both days. Scenario 2 shows that the median of the average waiting time is 35 minutes on Wednesday and a little over 25 minutes on Sunday. The medians from Scenario 3 are almost identical for both simulated days, approximating around 30 minutes of the average waiting time. Considering the morning and afternoon/evening rush hours, the results obtained from Scenario 2 are relevant to the collected data and observation during the crossing trips. The average waiting time on weekday is usually higher by a few minutes in comparison to the average waiting time on weekends. However, the results from Scenario 3 on

Sunday did not shown any improvement in the average waiting time in comparison to Scenario 2. Furthermore, the average waiting time is even higher in Scenario 3 which may be again caused by delay in reaction to the arriving pedestrian volume.

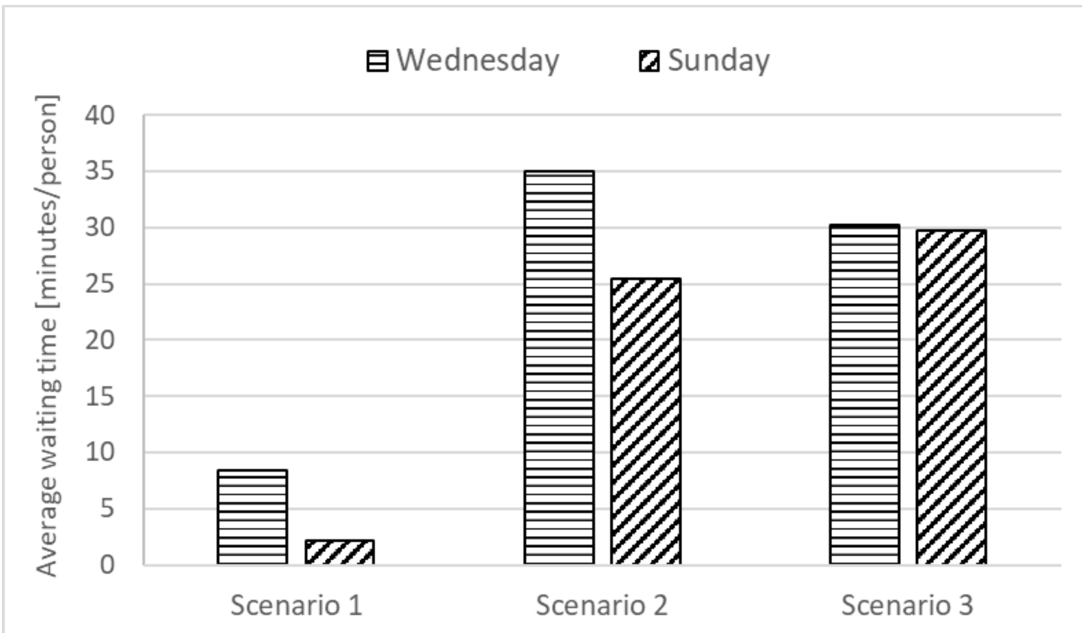

Figure 5.10 – Median average waiting time in the general lanes.

Chapter 6: Conclusion

This chapter concludes the thesis by providing a summary of the findings, limitations and challenges encountered, recommendation for management of northbound pedestrian crossing at the PDN POE, and suggestions on possible future research in this topic.

6.1 Summary of Findings

The thesis was dedicated to the topic of the border crossing from Ciudad Juarez to El Paso. The focus of the research was on the simulation modeling of the northbound pedestrian border crossing at the PDN POE. After review of the general background of the U.S-Mexico border crossing, the necessary data at the PDN POE was collected. The collected data were used to code the simulation model in AnyLogic, as the model's inputs and also for evaluation and comparison of the obtained outputs. Three different scenarios were created, simulated and the results analyzed.

The thesis compared three different scenarios of the northbound pedestrian border crossing at the PDN POE. Two groups of actors could benefit from the findings of this research. The first group of actors is the officers representing the organizations working on the border and taking care of the border crossing service (e.g., the CBP). These actors involved in the border crossing process may use the scenario experimented in the simulations. Secondly, the pedestrians themselves can benefit from a reduction in the waiting times.

6.2 Challenges

There are a few constraints that were encountered during this research. The biggest challenge was to obtain relevant and correct information on the border crossing: the process and statistics. Since border security policy contains many sensitive information and is not part of public knowledge, obtaining the required background was complicated.

6.3 RECOMMENDATIONS

This section provides recommendations on pedestrian northbound border crossing based on the results obtained in the previous chapter.

Proposed suggestions are for the general lanes only because neither in the SENTRI lane or in the Student lane were observed high waiting times or long queue length. Based on the analysis of the average waiting time and queue length in the general lanes, the increase in the number of the inspection booths is highly recommended on weekdays during the usual morning peak hours from about 5:00 a.m. to 8:00 a.m. and during the afternoon/evening rush hours from about 3:00 p.m. to 6:00 p.m. Besides the rise for the morning peak hours, the same would apply for the improvement of situation on weekends. Based on the outcomes of the average waiting times for Sunday (attached in the Appendix), the Scenario 3 provided almost the same trend as in case of Scenario 1 which features with all the inspection booths opened. Thus, the increase of the number of the inspection booths to maximum of nine during the afternoon/evening peak hours from about 3:00 p.m. to 7:00 p.m. is recommended. If applied, the maximal waiting time in the general lanes during the afternoon/evening rush hours on Sundays would be approximately 33 minutes.

To sum up, the adjustments in the schedule of open inspection booths for the general lanes during the morning and afternoon/evening peak hours are recommended based on the simulation outcomes. The proposed increase in the number of open inspection booths may be reflected in a decrease in the average waiting times in the general lanes at the inspection area for the majority of pedestrians.

6.4 Suggestions for Future Research

The thesis has simulated only the northbound pedestrian border crossing at one selected port of entry. Two approaches could be applied to extend the current model. One of the extensions can include developing a bigger model for the entire El Paso-Ciudad Juarez border area which would include multiple interconnected ports of entry. Another approach is to continue with the designed model by including other transportation modes such as passenger cars within the same POE.

Another potential research direction is to study the sensitivity of the input variables and parameters in the simulation. This approach can account for uncertainties in the input data (which are, as mentioned, the major limitations). One example is to adjust the percentage of queue length in the logic model of Scenario 3 to find out the optimal thresholds for the dynamics of opening and closing inspection booths.

Moreover, the simulation model may be used to predict waiting time and queue length for display in a border crossing smartphone application.

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Glossary

POE = port of entry

PDN = Paso del Norte (one of POE in El Paso-Ciudad Juarez)

BOTA = Bridge of the Americas (one of POE in El Paso-Ciudad Juarez)

IBCS = International Bridges Crossborder Survey

DCL = Dedicated Commuter Lane

POV = privately owned vehicle, i.e., passenger car

IBWC = International Boundary and Water Commission

CBP = U.S. Customs and Border Protection

RFID = Radio Frequency Identification

BTS = Bureau of Transportation Science

UTEP = University of Texas at El Paso

Appendix – Results of Simulation Experiments

Table A1 Model performance for Scenario 1 on Wednesday

Time	No. of booths			Average queue length (persons)			Average waiting time (minutes)		
	General	SENTRI	Student	General	SENTRI	Student	General	SENTRI	Student
12:00 a.m.	9	2	2	1	1	1	0	0	0
1:00 a.m.	9	2	2	3	1	0	0	0	0
2:00 a.m.	9	2	2	1	1	1	0	0	0
3:00 a.m.	9	2	2	2	1	1	0	0	0
4:00 a.m.	9	2	2	21	2	2	2	0	1
5:00 a.m.	9	2	2	54	4	1	7	1	0
6:00 a.m.	9	2	2	132	9	2	18	3	1
7:00 a.m.	9	2	2	176	7	1	31	3	0
8:00 a.m.	9	2	2	136	2	1	29	0	0
9:00 a.m.	9	2	2	112	3	1	20	1	0
10:00 a.m.	9	2	2	131	4	1	21	1	0
11:00 a.m.	9	2	2	120	2	1	24	1	0
12:00 p.m.	9	2	2	50	2	1	11	0	0
1:00 p.m.	9	2	2	9	1	1	1	0	0
2:00 p.m.	9	2	2	9	2	1	0	0	0
3:00 p.m.	9	2	2	8	2	1	0	0	0
4:00 p.m.	9	2	2	8	2	1	0	0	0
5:00 p.m.	9	2	2	10	2	1	0	0	0
6:00 p.m.	9	2	2	7	1	1	0	0	0
7:00 p.m.	9	2	2	3	1	1	0	0	0
8:00 p.m.	9	2	2	4	1	1	0	0	0
9:00 p.m.	9	2	2	3	1	1	0	0	0
10:00 p.m.	9	2	2	2	1	1	0	0	0
11:00 p.m.	9	2	2	2	1	1	0	0	0

Table A2 Model performance for Scenario 1 on Sunday

Time	No. of booths			Average queue length (persons)			Average waiting time (minutes)		
	General	SENTRI	Student	General	SENTRI	Student	General	SENTRI	Student
12:00 a.m.	9	2	2	2	1	1	0	0	0
1:00 a.m.	9	2	2	2	1	1	0	0	0
2:00 a.m.	9	2	2	3	1	1	0	0	0
3:00 a.m.	9	2	2	2	1	0	0	0	0
4:00 a.m.	9	2	2	2	1	1	0	0	0
5:00 a.m.	9	2	2	3	1	1	0	0	0
6:00 a.m.	9	2	2	3	1	1	0	0	0
7:00 a.m.	9	2	2	5	1	1	0	0	0
8:00 a.m.	9	2	2	5	1	1	0	0	0
9:00 a.m.	9	2	2	10	2	1	0	0	0
10:00 a.m.	9	2	2	12	3	1	0	1	0
11:00 a.m.	9	2	2	10	2	1	1	0	0
12:00 p.m.	9	2	2	19	2	2	2	0	1
1:00 p.m.	9	2	2	14	1	1	1	0	0
2:00 p.m.	9	2	2	97	14	2	9	5	1
3:00 p.m.	9	2	2	187	23	2	30	11	1
4:00 p.m.	9	2	2	180	7	1	34	6	0
5:00 p.m.	9	2	2	176	0	1	32	0	0
6:00 p.m.	9	2	2	164	2	1	32	0	0
7:00 p.m.	9	2	2	81	1	1	21	0	0
8:00 p.m.	9	2	2	9	1	1	1	0	0
9:00 p.m.	9	2	2	4	1	1	0	0	0
10:00 p.m.	9	2	2	3	1	1	0	0	0
11:00 p.m.	9	2	2	2	1	1	0	0	0

Table A3 Model performance for Scenario 2 on Wednesday

Time	No. of booths			Average queue length (persons)			Average waiting time (minutes)		
	General	SENTRI	Student	General	SENTRI	Student	General	SENTRI	Student
12:00 a.m.	2	2	2	1	1	1	0	0	0
1:00 a.m.	2	2	2	2	1	1	0	0	0
2:00 a.m.	2	2	2	3	1	1	0	0	0
3:00 a.m.	2	2	2	2	1	1	1	0	0
4:00 a.m.	7	2	2	26	3	1	3	1	0
5:00 a.m.	7	2	2	83	6	1	13	2	0
6:00 a.m.	7	2	2	173	11	2	29	4	1
7:00 a.m.	9	2	2	176	9	1	35	4	0
8:00 a.m.	9	2	2	169	2	1	30	0	0
9:00 a.m.	7	2	2	172	3	1	34	1	0
10:00 a.m.	7	2	2	187	4	1	40	1	0
11:00 a.m.	7	2	2	181	2	1	42	1	0
12:00 p.m.	7	2	2	182	2	1	41	0	0
1:00 p.m.	7	2	2	166	1	1	40	0	0
2:00 p.m.	7	2	2	154	2	1	36	0	0
3:00 p.m.	7	2	2	138	2	1	32	0	0
4:00 p.m.	5	2	2	132	2	1	36	0	0
5:00 p.m.	5	2	2	162	2	1	45	0	0
6:00 p.m.	5	2	2	163	1	1	53	0	0
7:00 p.m.	5	2	2	105	1	1	48	0	0
8:00 p.m.	5	2	2	27	1	1	18	0	0
9:00 p.m.	2	2	2	5	1	1	3	0	0
10:00 p.m.	2	2	2	4	1	1	1	0	0
11:00 p.m.	2	2	2	4	1	1	1	0	0

Table A4 Model performance for Scenario 2 on Sunday

Time	No. of booths			Average queue length (persons)			Average waiting time (minutes)		
	General	SENTRI	Student	General	SENTRI	Student	General	SENTRI	Student
12:00 a.m.	2	2	2	2	1	1	0	0	0
1:00 a.m.	2	2	2	2	1	1	1	0	0
2:00 a.m.	2	2	2	2	1	1	1	0	0
3:00 a.m.	2	2	2	2	1	1	1	0	0
4:00 a.m.	2	2	2	3	1	1	1	0	0
5:00 a.m.	2	2	2	4	1	1	2	0	0
6:00 a.m.	6	2	2	2	1	1	0	0	0
7:00 a.m.	6	2	2	4	1	1	0	0	0
8:00 a.m.	6	2	2	6	1	1	0	0	0
9:00 a.m.	6	2	2	25	2	1	4	0	0
10:00 a.m.	6	2	2	50	3	1	11	1	0
11:00 a.m.	6	2	2	74	2	1	18	0	0
12:00 p.m.	7	2	2	93	2	1	18	0	0
1:00 p.m.	7	2	2	102	1	1	24	0	0
2:00 p.m.	9	2	2	143	7	1	19	2	0
3:00 p.m.	9	2	2	194	17	2	33	7	1
4:00 p.m.	9	2	2	192	9	1	35	5	0
5:00 p.m.	6	2	2	184	2	1	40	0	0
6:00 p.m.	6	2	2	177	2	1	43	0	0
7:00 p.m.	6	2	2	172	1	1	42	0	0
8:00 p.m.	6	2	2	144	1	1	38	0	0
9:00 p.m.	2	2	2	112	1	1	37	0	0
10:00 p.m.	2	2	2	68	1	1	40	0	0
11:00 p.m.	2	2	2	25	1	1	34	0	0

Table A5 Model performance for Scenario 3 on Wednesday

Time	No. of booths			Average queue length (persons)			Average waiting time (minutes)		
	General	SENTRI	Student	General	SENTRI	Student	General	SENTRI	Student
12:00 a.m.	2	2	2	1	1	1	0	0	0
1:00 a.m.	2	2	2	1	1	1	0	0	0
2:00 a.m.	2	2	2	1	1	1	0	0	0
3:00 a.m.	2	2	2	1	1	1	0	0	0
4:00 a.m.	2	2	2	93	2	1	20	0	0
5:00 a.m.	5	2	2	193	4	1	56	1	0
6:00 a.m.	8	2	2	173	8	1	47	3	0
7:00 a.m.	9	2	2	169	6	1	31	3	0
8:00 a.m.	9	2	2	169	2	1	31	0	0
9:00 a.m.	9	2	2	169	3	1	31	1	0
10:00 a.m.	9	2	2	168	4	1	31	1	0
11:00 a.m.	9	2	2	169	2	1	31	1	0
12:00 p.m.	9	2	2	171	2	1	31	0	0
1:00 p.m.	9	2	2	173	1	1	31	0	0
2:00 p.m.	9	2	2	125	2	1	28	0	0
3:00 p.m.	8	2	2	65	2	1	16	0	0
4:00 p.m.	4	2	2	51	1	1	13	0	0
5:00 p.m.	3	2	2	134	2	1	32	0	0
6:00 p.m.	6	2	2	157	2	1	50	0	0
7:00 p.m.	6	2	2	62	1	1	31	0	0
8:00 p.m.	3	2	2	14	1	1	10	0	0
9:00 p.m.	2	2	2	16	1	1	13	0	0
10:00 p.m.	2	2	2	6	1	1	5	0	0
11:00 p.m.	2	2	2	4	1	1	2	0	0

Table A6 Model performance for Scenario 3 on Sunday

Time	No. of booths			Average queue length (persons)			Average waiting time (minutes)		
	General	SENTRI	Student	General	SENTRI	Student	General	SENTRI	Student
12:00 a.m.	2	2	2	3	1	1	1	0	0
1:00 a.m.	2	2	2	2	1	1	1	0	0
2:00 a.m.	2	2	2	3	1	1	1	0	0
3:00 a.m.	2	2	2	2	1	1	1	0	0
4:00 a.m.	2	2	2	2	1	1	0	0	0
5:00 a.m.	2	2	2	3	1	1	1	0	0
6:00 a.m.	2	2	2	3	1	1	1	0	0
7:00 a.m.	2	2	2	25	1	1	11	0	0
8:00 a.m.	2	2	2	71	1	1	33	0	0
9:00 a.m.	3	2	2	166	2	1	57	0	0
10:00 a.m.	7	2	2	181	2	1	58	0	0
11:00 a.m.	9	2	2	172	2	1	34	0	0
12:00 p.m.	9	2	2	161	3	1	31	1	0
1:00 p.m.	9	2	2	107	2	1	25	0	0
2:00 p.m.	8	2	2	134	11	2	17	4	1
3:00 p.m.	9	2	2	186	22	2	35	9	1
4:00 p.m.	9	2	2	180	14	1	33	8	0
5:00 p.m.	9	2	2	175	3	1	32	1	0
6:00 p.m.	9	2	2	174	2	1	32	0	0
7:00 p.m.	9	2	2	114	1	1	27	0	0
8:00 p.m.	6	2	2	26	1	1	6	0	0
9:00 p.m.	3	2	2	17	1	1	9	0	0
10:00 p.m.	2	2	2	11	1	1	9	0	0
11:00 p.m.	2	2	2	5	1	1	7	0	0

Vita

Eliska Glaserova was born in Usti and Orlici, the Czech Republic, in 1997. She graduated from the Faculty of Transportation Science at Czech Technical University in Prague (CTU) in 2019. Her Bachelor's study program was Technology in Transportation and Telecommunications with a specialization on Logistics and Transport Processes Control. Her bachelor thesis defense "Concept of Technological Processes on a Railway Track Litoměřice – Most".

In 2020, she enrolled in the Dual Master Degrees Program in Smart Cities that is based on a collaboration between CTU and The University of Texas at El Paso (UTEP). After finishing the first year at CTU, she continued with her studies at UTEP.

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