EL PASO – CIUDAD JUAREZ SMART BORDER TRANSPORTATION SYSTEM

ARCHITECTURE

KATERINA PITHARTOVA

Master's Program in Engineering

APPROVED:

Ruey Long Cheu, Ph.D., Chair

Carlos M. Ferregut, Ph.D.

Tomas Horak, Ph.D.

Miroslav Svitek, Ph.D.

Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School

EL PASO – CIUDAD JUAREZ SMART BORDER TRANSPORTATION SYSTEM ARCHITECTURE

by

KATERINA PITHARTOVA

GRADUATE PROJECT

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Engineering Education and Leadership

THE UNIVERSITY OF TEXAS AT EL PASO

May 2022

CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Transportation Sciences
Dean's office
Konviktská 20, 110 00 Prague 1, Czech Republic

K617 ..... **Department of Logistics and Management of Transport**

MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

Bc. Kateřina Pithartová

Study programme (field/specialization) of the student:

master's degree – SC – Smart Cities

Theme title (in Czech): **Návrh systémové architektury Smart Border El Paso - Ciudad Juarez**

Theme title (in English): **El Paso - Ciudad Juarez Smart border transportation system architecture**

Guidelines for elaboration

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

- Analyze and describe the current state of the El Paso - Ciudad Juarez border system
- Identify the main actors related to the El Paso - Ciudad Juarez border crossing system
- Identify and describe the core services of the El Paso - Ciudad Juarez border crossing system
- Prepare the conceptual proposal of the knowledge map describing the El Paso - Ciudad Juarez border crossing system

Graphical work range: N/A

Accompanying report length: At least 55 pages

Bibliography:

U.S. Customs and Border Protection STRATEGY 2021–2026. U.S. Customs and Border Protection, 2020

NOY, Natalya F.; MCGUINESS, Deborah L. Ontology Development 101: A Guide to Creating Your First Ontology. Stanford University

Master's thesis supervisor: **doc. Ing. Tomáš Horák, Ph.D.**
prof. Dr. Ing. Miroslav Svítek, dr. h. c.
Ruey Long Cheu, Ph.D.

Date of master's thesis assignment: **June 30, 2021**
(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)

Date of master's thesis submission: **May 16, 2022**
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.

doc. Ing. Tomáš Horák, Ph.D.
head of the Department
of Logistics and Management of Transport

prof. Ing. Ondřej Přibyl, Ph.D.
dean of the faculty

I confirm assumption of master's thesis assignment.

Bc. Kateřina Pithartová
Student's name and signature

Prague ..... May 3, 2022

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.

This research is jointly supervised by the following faculty members:

Ruey Long Cheu, Ph.D., The University of Texas at El Paso

Carlos M. Ferregut, Ph.D., The University of Texas at El Paso

Tomas Horak, Ph.D., Czech Technical University in Prague

Miroslav Svítek, Ph.D., Czech Technical University in Prague

Acknowledgements

Firstly, I would like to thank my parents for supporting me during my studies.

Secondly, I would like to thank all professors that helped me and led me during my studies, especially my advisors Dr. Ruey Long Cheu, The University of Texas at El Paso, and Dr. Tomas Horak, Czech Technical University in Prague.

Thirdly, I would like to thank prof. Ing. Ondrej Pribyl, Ph.D. for providing me with valuable consultations related to the Unified Modeling Language, and Dr. Natalia Villanueva Rosales for consultations related to the ontology. Moreover I would like to thank Lidice Castro and Eliska Glaserova who were my team mates in a class project focused on developing the early version of the ontology.

Lastly, I would like to help all my friends for helping me and supporting me, especially my classmates in the BIG LAB in El Paso.

Abstrakt

Hlavním cílem práce je poskytnout systematizovanou a strukturovanou rerši komplexního systému hraničních přechodů mezi americkým městem El Paso v Texasu a mexickým Ciudad Juarez. Potřeba vzniku práce vzešla na základě nedostatečné informovanosti o této problematice. Přeshraniční styk má klíčový význam pro obyvatele obou měst, El Pasa i Ciudad Juarez. Diplomová práce by měla sloužit jako zdroj důležitých informací pro širokou škálu projektů v souvislosti s touto problematikou.

Práce shrnuje informace o americko-mexických hraničních přechodech, jejich hlavních prvcích a procesech. Dále práce popisuje hraniční přechody v oblasti El Paso – Ciudad Juarez a jejich hlavní charakteristiky. Pro grafické znázornění a popis architektury hraničního přechodu ve více úrovních byl využit SW nástroj Unified Modelling Language (UML) a byla vytvořena základní ontologie hraničního přechodu.

Klíčová slova:

Hraniční přechod, systémová architektura, vstupní bod, Unified Modeling Language, ontologie

Abstract

The main purpose of the thesis is to provide a systematized and structured source of information about the border crossing system between El Paso, Texas, and Ciudad Juarez, Mexico. The need for the thesis was identified because, at the time of the research, there is an information gap in this area identified. Moreover, the border crossing is a very important topic for people living in El Paso or Ciudad Juarez, so the thesis can be used as a source of important information for several types of projects.

The thesis describes the overall information about the U.S. - Mexico border crossings, its actors, and main services. Additionally, it also describes the Ports of entry in El Paso - Ciudad Juarez and their characteristics. Secondly, the Unified Modelling Language is used to graphically represent and describe the architecture of the border crossing on multiple levels of detail. Lastly, the core of border crossing ontology is proposed.

Keywords:

Border crossing, system architecture, port of entry, Unified Modeling Language, ontology

Contents

1. Introduction

1.1 Background

The Border Crossing

The border crossing system along the U.S.-Mexico international border is a complex system that involves multiple organizations from the two countries working to moderate the flow of people and goods across the border.

The system is complex, not only because of a variety of actors but also because of the high variability in the processes. The process of crossing southbound (from the United States to Mexico) is different from the process of crossing northbound (from Mexico to the U.S.). There are different document and inspection requirements for the travelers, passenger vehicles, and commercial vehicles. Crossing the border in northbound direction is generally more complicated than crossing in the opposite direction. There are three "modes" of travel available for the northbound crossing:

- By foot (pedestrian)
- By passenger vehicle
- By commercial vehicle (truck)

The infrastructure for pedestrian crossing and passenger vehicle crossing are usually located next to each other, but the infrastructure for commercial vehicle crossing is usually separated

from the facility for pedestrian and passenger vehicle, since it requires a special equipment to execute the legally mandated inspection procedure.

Unlike the southbound crossing, the northbound crossing has multiple types of inspection booths (called lane types), that serve specific types of travelers. Different types of lanes with different requirements enable to speed up the inspection for selected types of travelers.

To sum up the brief introduction, the thesis/report will provide a systematized description of the northbound border crossing system, as well as detailed descriptions of selected components of the system. The challenge of this research is the lack of publicly available information on the border crossing system. Based on the available literature that are sometimes available only in Spanish or English, together with common experiences of the frequent cross-border travelers, this these/report provides a systematic description of the system to fill the information gap.

Unified Modelling Language

Unified Modelling Language (UML) is a language that uses standardised ways to visualize a system or system design. In thesis/report, various UML diagrams are used to map the structure of the border crossing system as well as describing the workflow of its components. The main advantage of UML is that is that it provides an organized visual description of the complex system as well as its parts. This tool (UML) is mostly used during the software design, but it can be also used in to map existing systems (like in this thesis/report).

Ontology

Ontology is the description of certain knowledge of a system in a machine-readable way. By linking data in a web, ontology allows sharing and linking of common knowledge. It is also possible to query the system, to infer knowledge based on linking multiple information. The analysis of transportation systems often requires linking data from multiple sources. The advantage of using ontology in transportation is the sharing common knowledge using several data sets. This could be very helpful for example in case of decision making.

1.2 Research objectives

The research has three objectives. The first objective is to collect information from available sources, frequent travelers, by observation and structured interviews about the system of the border crossing between Ciudad Juarez, Chihuahua, Mexico and the City of El Paso, Texas, U.S., to provide systematized broad source of information for additional research of the border crossing system.

The second objective is to use Unified Modelling Language to graphically represent the border crossing services, actors, activities and their interactions. This tool will be used because it is widely used and recognised, so it eliminates a future misunderstanding of the diagrams.

The third objective is to propose a core ontology that contains all the objects in selected border crossing system that are organized into classes, with the relationships between classes. The use of this ontology to answer queries is illustrated via several examples. The core of the proposed ontology can be extended in the future, based on the specific needs of the additional researches.

1.3 Outline

Chapter 1 serves as an introduction of this thesis/report.

Chapter 2 describes the ports of entry, their infrastructure, available services.

Chapter 3 continues with describing the government organizations related to the border crossing in El Paso-Ciudad Juarez.

Chapter 4 describes UML and its diagrams used in the thesis, together with ontology which was also designed for the purposes of the thesis.

Chapter 5 focuses on describing border crossing system using UML diagrams with multiple levels of detail.

Chapter 6 introduces the core of ontology of the ports of entry, it's infrastructure and types of travelers together with their limitations.

Finally, the Chapter 7 concludes the work and provides the possible areas of future research.

2. Ports of Entry on the U.S.-Mexico Border

Ports of Entry (POEs) are defined by the U.S. General Service Administration as "facility that provides controlled entry into or departure from the United States for persons or materials."[1] The main purposes of POEs are (i) to moderate and facilitate trade and people influence into the U.S; (ii) to prevent terrorism; and (iii) to assure the legitimacy of the goods and the imported into the U.S.

The infrastructure of the POEs can be owned and maintained by variable entities e.g. cities and/or counties, federal government, or private owners [2], but the organization responsible for the security and facilitating operations at ports of entry is the Custom Border Protection (CBP).

The ports of entry can be generally divided into three groups based on the mode of transportation into the U.S.:

- land port of entry
- sea port of entry
- air port of entry

There are in total 328 ports of entry in United States, and 47 out of the 328 are land ports of entry located on the border between U.S. and Mexico [2]. The master's thesis is focused

on four land ports of entries, located along the U.S.-Mexico border between the City of El Paso, Texas and Ciudad de Juarez, Chihuahua.

2.1 Types of Traveler-Lanes

The influence of goods and people to the inspection booth before entering the United States is moderated, by dividing the flow into several lanes which are based on the type of the traveler. This lane characterizes and modifies the process of the inspection, helps to speed the flow up as well as it enables to prioritize selected travelers in the entering process.
At the POEs along the U.S.-Mexico border, there are four types of lanes. Table 2.1 describes the possible types of lanes each type of traveler can use.

Table 2.1: Types of available lanes for each type of traveler.

Type of traveler	**Types of Lane**
Pedestrians	General lane
	SENTRI lane
	Ready lane
Passenger vehicles	General lane
	Ready lane
	SENTRI lane
Commercial vehicles	General lane
	FAST lane

SENTRI lane

The SENTRI Lane is also known as Dedicated Commuter Lane [3]. This type of lane is dedicated only to the pre-approved passenger vehicle drivers and pedestrians, that are considered as eligible and low risk. To be able to use the lane, the traveler must be registered in the Trusted Traveler Program.

The pre-approval process is based on the registration into the Trusted Traveler Program, and completing an interview with the CBP officer, to ensure the eligibility of the traveler to obtain the pre-approval. After completing the steps, travelers are usually not interviewed during the general crossing process. This helps speed up the crossing process and significantly fastens the flow of the pre-approved travelers.

FAST lane

The FAST lane s a shortcut for Free and Secure Trade lane is a special lane available only for commercial vehicles [4]. The lane is dedicated only for travelers registered in the trusted traveler program, that proved the eligibility in an initial background check [4]. Moreover, the services is also available for vehicles of CBP partner companies that are in Customs Trade Partnership Against Terrorism program [5].

Ready lane

The Ready lane is, in comparison to FAST and SENTRI lane, not part of the Trusted Traveler Program. The lane is design to speed the process by adding step of scanning the traveler's document, before entering the booth. At the time of entering the booth,

all the required records from the databases will be already available for the CBP officer. To use the lane, it requires to have a Radio Frequency Identification enabled document (U.S. Passport Cards, Enhanced Driver's Licenses, Enhanced Tribal Cards, Enhanced Border Crossing Cards, Enhanced Permanent Resident Cards, and Trusted Traveler Program cards). The service is available for passenger vehicle passengers and pedestrians [6].

Trusted Traveler Program

Trusted Traveler Program is a prepaid program for pre-approved eligible and trusted travelers, that significantly speeds up the border control process. The program covers 5 types of membership based on the required type of port of entry and type of the traveler. The supported types of memberships are: Global Entry, TSA PreCheck, SENTRI, NEXUS, and FAST. The membership available for commuters in El Paso are FAST for commercial vehicle drivers and SENTRI for pedestrians and passenger vehicle drivers [7].

Customs Trade Partnership Against Terrorism

The Customs Trade Partnership Against Terrorism is a service provided by the U.S. Customs and Border Protection to international supply chains. The partnership is according to the CBP websites focused on providing the highest level of cargo security only through close cooperation with the principle stakeholders of the international supply chain [5].

To join the partnership, the private sector must implement specific security measures and best practices by the U.S. Customs and Border Protection [5]. This ensures the private sector companies to be considered as low-risk, which enables them to use several benefits.

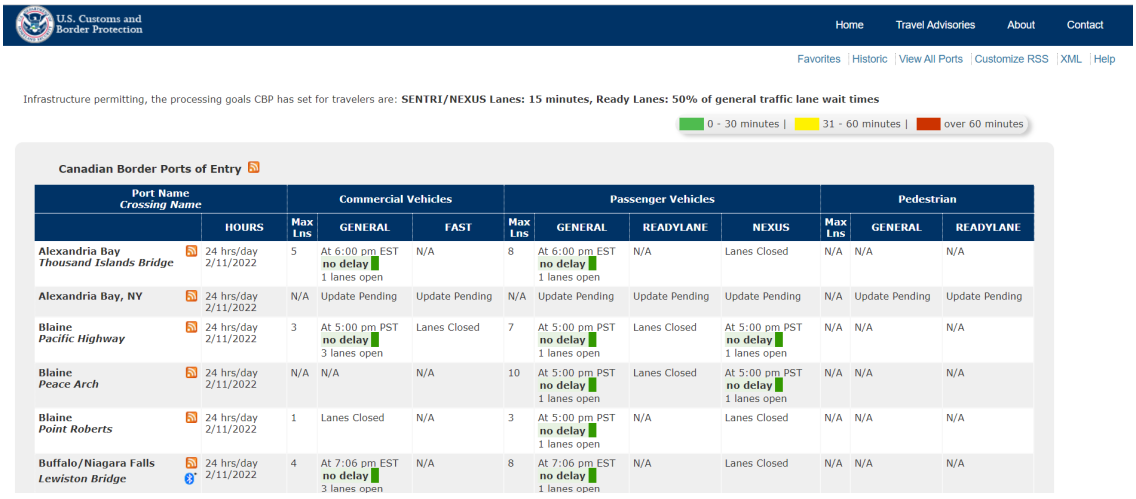
The CBP websites lists several benefits of this partnership. The main benefits regarding the

border crossing inspection are:

- Reduced number of CBP examinations
- Front of the line inspections
- Possible exemption from Stratified Exams
- Shorter wait times at the border
- Access to the Free and Secure Trade (FAST) Lanes at the land borders [**ctpat**]

2.1.1 Border Wait Times

Border Wait Times is a service provided to the travelers my the Customs and Border Protection. It is publicly available online on the website (https://bwt.cbp.gov/), or as a mobile app. The GUI of the web page is shown in Figures 2.1 and 2.2. The service provides actual as well as historical data of wait times for each POE. The wait times are estimated by visual inspection of the queue length by CBP officers.



Port Name / Crossing Name	HOURS	Commercial Vehicles			Passenger Vehicles				Pedestrian		
		Max Lns	GENERAL	FAST	Max Lns	GENERAL	READYLANE	NEXUS	Max Lns	GENERAL	READYLANE
Alexandria Bay *Thousand Islands Bridge*	24 hrs/day 2/11/2022	5	At 6:00 pm EST no delay 1 lanes open	N/A	8	At 6:00 pm EST no delay 1 lanes open	N/A	Lanes Closed	N/A	N/A	N/A
Alexandria Bay, NY	24 hrs/day 2/11/2022	N/A	Update Pending	Update Pending	N/A	Update Pending	Update Pending	Update Pending	N/A	Update Pending	Update Pending
Blaine *Pacific Highway*	24 hrs/day 2/11/2022	3	At 5:00 pm PST no delay 3 lanes open	Lanes Closed	7	At 5:00 pm PST no delay 1 lanes open	Lanes Closed	At 5:00 pm PST no delay 1 lanes open	N/A	N/A	N/A
Blaine *Peace Arch*	24 hrs/day 2/11/2022	N/A	N/A	N/A	10	At 5:00 pm PST no delay 1 lanes open	Lanes Closed	At 5:00 pm PST no delay 1 lanes open	N/A	N/A	N/A
Blaine *Point Roberts*	24 hrs/day 2/11/2022	1	Lanes Closed	N/A	3	At 5:00 pm PST no delay 1 lanes open	N/A	Lanes Closed	N/A	N/A	N/A
Buffalo/Niagara Falls *Lewiston Bridge*	24 hrs/day 2/11/2022	4	At 7:06 pm EST no delay 3 lanes open	N/A	8	At 7:06 pm EST no delay 1 lanes open	N/A	Lanes Closed	N/A	N/A	N/A

Figure 2.1: Border Wait Times - web GUI

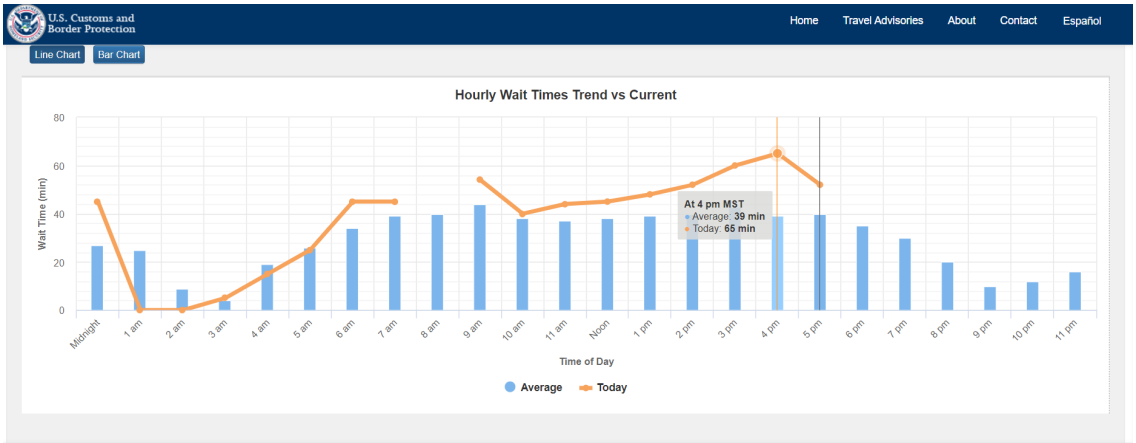


Figure 2.2: Border Wait Times - web GUI

2.2 Ports of Entry in the City of El Paso

The international border between Ciudad Juarez and the City El Paso was historically set by the river Rio Grande. Based on this fact, the local POEs are characteristic the way, that the two countries are connected via bridges across the Rio Grande. For the system modeling purposes, each POE is characterized by number of available booths and number of available vehicle lanes.

The two cities are connected via four POEs that operate 24 hours a day, seven days a week. There are 2 POEs located in the city center – Paso del Norte and Stanton . The BOTA POE is located in the eastern part of downtown and Yelsta POE is located on the south-eastern outskirt of El Paso.

Additionally, there is also one port of entry situated on the west from El Paso in the State of New Mexico. This POE is called Santa Teresa. The thesis will not be focused on this POE, for several reasons:

- The POE is not located on the border of the City of El Paso and Ciudad Juarez, but its

situated between the cities Santa Teresa, New Mexico and San Jerónimo, Chihuahua.

- The POE operates in a limited hours – from 6 a.m. until midnight daily.
- The volume of the traffic compared to the other four POEs is significantly lower.

The four El Paso's POEs can provide services for:

- Pedestrians
- Non-commercial (passenger) vehicles
- Commercial vehicles

Table 2.3 lists the number of inspection booths that serve pedestrians, non-commercial vehicles and commercial vehicles crossing in the northbound direction.

Table 2.2: Infrastructure of the booths for northbound crossing for each POE

Port of entry	**Pedestrian**	**Passenger vehicle**	**Commercial vehicle**
Paso del Norte	14	12	0
Stanton Street Bridge	0	1 (SENTRI)	0
BOTA	4	14	6
Ysleta Bridge	4	12	10

2.2.1 Bridge Owners

The infrastructures of the Paso Del Norte, Ysleta, and Stanton POEs in the U.S. side are owned by the City of El Paso while on the Mexican site aare owned by the Federal Government

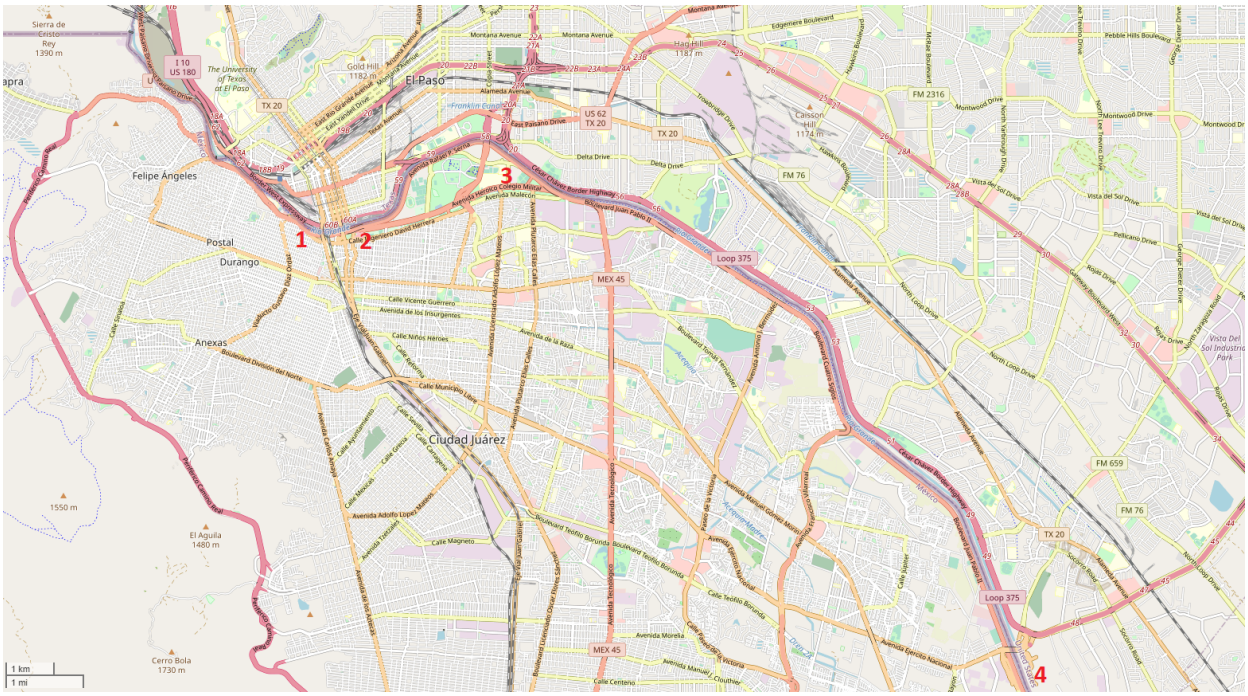


Figure 2.3: Ports of entry in El Paso: 1 – Paso del Norte Bridge, 2 – Staton Street Bridge, 3 – Bridge Of The Americas, 4 - Ysleta Bridge; source: Open Street Map, edited

of Mexico. The Bridge of the Americas (BOTA) POE is owned by the U.S. Section and the Mexican Section of the International Boundary and Water Commission, an entity established by both U.S. and Mexican governments. [2]

Table 2.3: Types of owners of the El Paso POE infrastructure.

U.S.	**Mexico**
City of El Paso	Government of Mexico
U.S. Section, International Boundary and Water Commission	Mexican Section, International Boundary and Water Commission

2.2.2 Toll System

Vehicles or persons crossing from Mexico to U.S. (northbound) or from the U.S. to Mexico (southbound) requires paying a toll. The only POE that offers toll-free for both southbound and northbound crossings is BOTA. The toll-free arrangement at BOTA is part of the treaty signed by the U.S. and Mexican governments. [2]

The organization responsible for collecting toll in the U.S. side of the Paso del Norte, Stanton and Ysleta POEs is The City of El Paso, specifically its International Bridges Department. The payment can be made in USD or Mexican peso, by cash, credit card or using a pre-paid toll program E-Fast Pass. On the Mexican side of the bridge is the responsible toll collection organization is called Fideicomiso de Puentes Fronterizos de Chihuahua [8].

E-Fast Pass is an electronic pre-paid toll program offered by the City of El Paso, that is used for southbound crossing. Travelers can purchase a tag and deposit a credit to open an account. The process can speed up of paying the toll. Moreover, the customers of E-Fast Pass enjoy lower toll rates. This service is available for passenger vehicles, pedestrians as well as commercial vehicles.

2.2.3 Paso del Norte POE

The Paso del Norte is one of the 2 POEs in the downtown of El Paso. It is located on 1000 S. El Paso Street. It is one of the oldest bridges originally built in 1800's. This POE provides possibility for non-commercial vehicle crossing from Mexico to U.S., but pedestrians can cross both ways. The infrastructure for northbound crossing consists of 12 booths for non-commercial vehicles and 14 booths for pedestrians. Commercial traffic crossing is not

available in this port of entry.[2]

Since the Paso del Norte POE is located in the downtown area, this port of entry is used by most of the pedestrians crossing the border between El Paso and Ciudad Juarez. During the year 2019 over 50% of the pedestrians (almost 2,2000,000) chose the Paso del Norte POE to cross between Ciudad Juarez and El Paso. Compared to Staton POE, which is the second POE located in the downtown area, the Paso del Norte POE has higher volume of non-commercial vehicles.

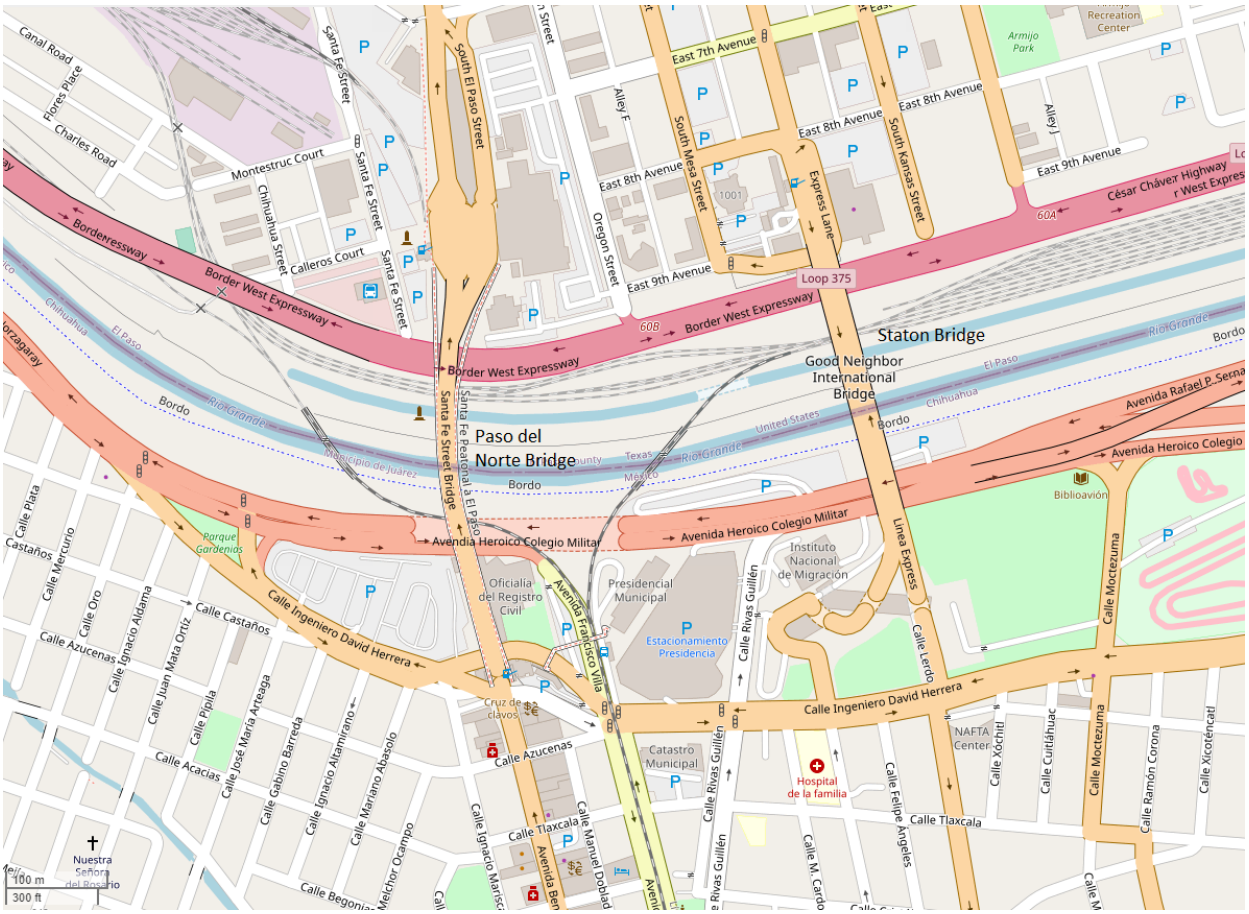


Figure 2.4: Ports of entry in downtown El Paso - Paso del Norte on the left, Staton Bridge on the right; source: Open Street Map, edited

2.2.4 Stanton POE

The Staton POE, also known as "Good Neighbor Bridge", is the second POE situated in the downtown area of El Paso. It is situated on the address of 1001 S. Stanton Street, and it lies less than 1000 feet from the Stanton bridge. This port of entry was first built in 1800's, and since that it was redesigned multiple times to suffice the increasing the inspection capacity or after damages due to flooding.[2]

This POE is primarily dedicated for the southbound crossing. The infrastructure for the northbound consists of 1 booth for SENTRI non-commercial vehicle crossing only. Based on the pre-covid northbound crossing statistics from 2019, this POE has the lowest volume of noon-commercial vehicle crossing, because of the limited infrastructure, that is designed for southbound crossing.

2.2.5 Bridge of the Americas POE

The Bridge of Americas is the only bridge that is from the U.S. side not owned and maintained by the City of El Paso, but by the U.S. Section of the International Boundary and Water Commission. The bridge connects the Mexican highway MX 45 and the American highway I-10 on the eastern part of the city, 2,5 miles from the downtown of El Paso, on the address 3600 E. Paisano. The bridge is in Spanish called "Puente Libre", since it is the only POE in El Paso that does not charge a toll for non-commercial vehicles and pedestrians). [2]

The infrastructure of the POE consists of 4 separate structures - 2 bridges for northbound and southbound commercial vehicles and 2 bridges for northbound and southbound non-passenger vehicles and pedestrians [2]. The northbound direction has 14 booths for non-commercial

vehicles, four booths for pedestrians and 6 booths for commercial traffic. These booths serve the FAST lanes, the Ready Lanes, as well as the SENTRI lanes.

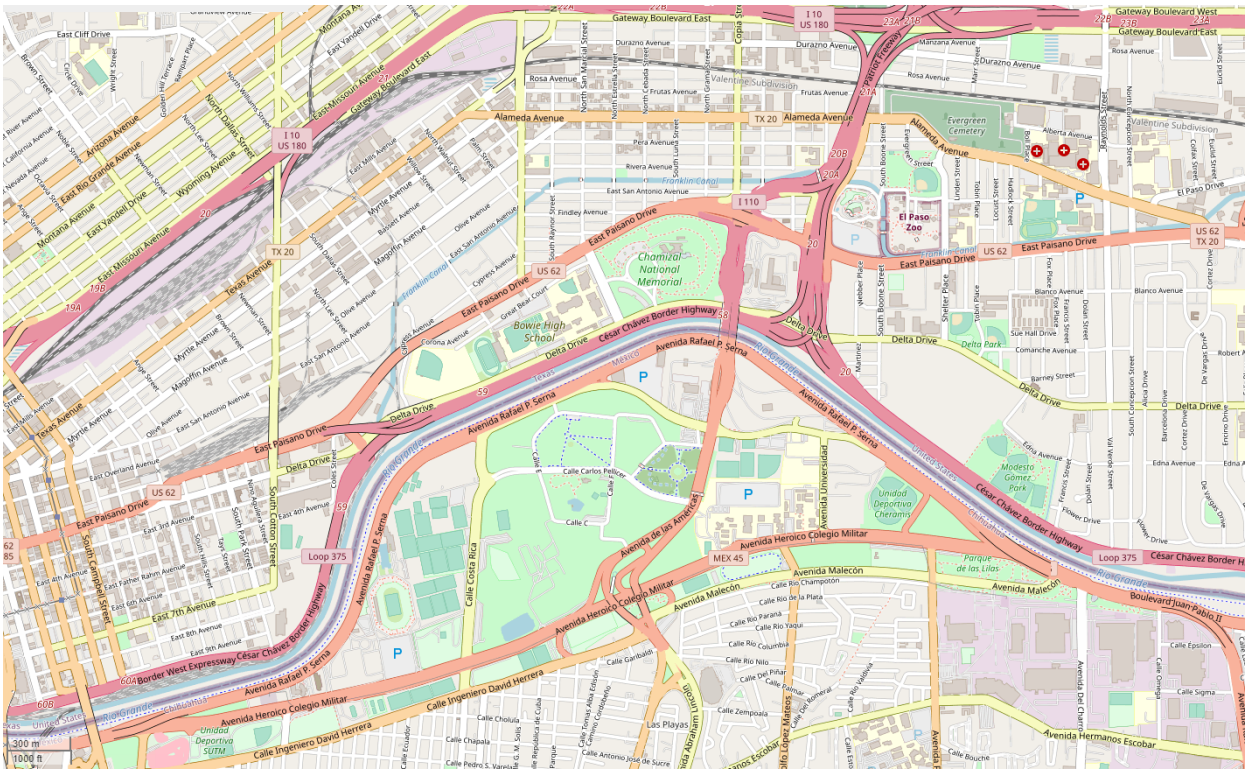


Figure 2.5: Bridge Of The Americas; source: Open Street Map

2.2.6 Ysleta POE

The Ysleta POE is also known as the Zaragoza POE or Zaragoza Bridge. It is located on the south-eastern part of El Paso, 10 miles from the downtown, on the address 791 S. Zaragoza. The bridge was originally constructed in 1938. Since then the POE was renovated and rebuilt several times [2]. The last renovation ended in 1990, and the bridge was redesigned into two bridges. The first bridge serves commercial traffic, and the second bridge serves for non-commercial vehicles and pedestrians.

For non-commercial vehicles, there are 12 booths dedicated for the northbound crossing. For

the pedestrian, there are 4 booths for northbound crossing. For commercial vehicles, there are 10 booths for northbound crossing. The booths serve the FAST lanes, the Ready Lanes as well as the SENTRI lanes.

Figure 2.6: Ysleta Bridge; source: Open Street Map

3. Government Organizations

3.1 U.S. Department of Homeland Security

The U.S. Department of Homeland Security (DHS) is a federal executive department, that was established in 2001 by President George Bush as a response to the 9/11 terrorist attacks [9]. The main missions of DHS are:

- Secure U.S. borders and approaches
- Counter terrorism and homeland security threats
- Secure cyberspace and critical infrastructure
- Preserve and uphold the nation's prosperity and economic security
- Strengthen preparedness and resilience [9].

The DHS consists of several components, and each component has its own mission and responsibility. The component that is important for this thesis is the Custom Border Protection (CBP).

The CBP is the largest component under DHS. The CBP primarily focuses on border control management, border security, and monitoring the inflow of people and goods into the country. The CBP was created in 2003 [10]. The mission of the CBP is to protect and safeguard the US borders and enhance the economic prosperity of the nation. The document CBP Protection Strategy 2021–2026 has identified five Enduring Mission Priorities: countering terrorism,

combating transnational crime, securing the border, facilitating lawful trade and protecting revenue, and facilitating lawful travel [10]. The CBP has large variety of law enforcement entities, but for the purposes of the thesis is important to explain who are CBP officers, and what is the difference between the Office of Field Operations and the Border Patrol.

The Office of Field Operations is a component under the CBP that focuses on border security. The CBP officer is a law enforcement position in the Office of Field Operations is responsible for managing and inspecting the flow of people and goods at the POEs. During a traveler's border crossing process, the field officer interacts with the traveler, interviews them, updates the records, and if necessary conducts the secondary inspection as well as handles goods declaration.

The Border Patrol agent is another component under the CBP but it focuses on securing international land borders and coastal waters between POEs. The Border Patrol agents do not interact with the travelers during the legal border crossing process.

3.2 Instituto Nacional de Migración

The Instituto Nacional de Migración is the Mexican federal authority responsible for monitoring the flow of people into Mexico, as well as administrating all services that are related to international travel for Mexican citizens and visitors. During the southbound crossing process, the Instituto Nacional de Migración officers interact with the travelers. [11]

3.3 Servicio de Administración Tributaria

The Servicio de Administración Tributaria is the federal organization in Mexico responsible for collecting tax on the Mexican side of the international borders and important cities. The Servicio de Administración Tributaria officers interact with the travelers with regards to import and export of goods.

3.4 Aduanas de Mexico

The Aduanas de Mexico are federal government offices at all of the Mexican side of the POEs where the Servicio de Administración Tributari operates together with Instituto Nacional de Migración. The facilities are equipped with all the necessary the infrastructure for inspection, tax payment and all actions related to immigration.

3.5 International Boundary and Water Commission

The International Boundary and Water Commission (IBWC) is, according to its official website, an international body, responsible for applying the rights and obligations under the boundary and water treaties between the U.s. and Mexico [12]. These include maintaining the BOTA POE. The Commission consists of two sections – the Mexican section and the U.S. section. Each section has its own head commissioner. The seat of the US section is situated in El Paso, Texas and the seat of the Mexican section is situated in Ciudad Juarez, Chihuahua. [12]

3.6 Texas Alcoholic Beverage Commission

The Texas Alcoholic Beverage Commission is the Texas state agency responsible for "all phases of regulating the alcoholic beverage industry in Texas, including sales, taxation, importation, manufacturing, transporting and advertising"[13].At a border crossing, a traveler who bring any kind of alcohol from Mexico into Texas must pay an import tax to the Texas Alacoholic Beverage Commission in a special booth.

3.7 City of El Paso

The City of El Paso's International Bridges Department is responsible for managing and maintaining the U.S. side of the international bridges that are linked to the Stanton, Paso del Norte and Ysleta POEs. Moreover, the department are collecting toll from travelers crossing in the southbound direction.

3.8 Fideicomiso de Puentes Fronterizos de Chihuahua

The Fideicomiso de Puentes Fronterizos de Chihuahua is an organization that represents the State of Chihuahua government in the maintenance of the Mexican side of the bridges at the Paso del Norte and Ysleta POEs. Moreover, this organization is responsible also for toll collection from travelers crossing in the northbound direction.

4. Methodology

This chapter describes the methodology used in this research. The first part of this chapter describes the system analysis approach. The second part of the chapter describes the Unified Modelling Language (UML) and ontology.

4.1 System Analysis Process

Analyzing the systems and processes at POEs are the key research tasks. It was important to fully understand the border crossing systems and processes, before starting to map the system architecture. Since the border crossing process is to server travelers, it was decided to map the architecture of the border crossing system only from user's point of view.

Secondly, structured interviews [1] with travelers who cross the border regularly were used to solicit and extract the core activities of the border crossing system. Based on the information from the initial structured interviews, the border crossing scenarios and services were created using software tools described in Section 4.2.

Thirdly, the information from the structured interviews were verified. The process of verification started with the author observing and experiencing the border crossing process herself. The draft use case diagrams were presented to frequent travelers, and modified based on their experiences, to ensure the diagrams represent the general practices.

[1] The interviews were conducted in El Paso with the approval of The University of Texas at El Paso Institutional Review Board

4.2 Mapping Techniques

This section describes the two techniques used for the mapping of the border crossing systems:

- Unified Modeling Language
- Ontology

The UML is used to describe the structure of the border crossing processes/activities using multiple layers of diagrams. The ontology is used to represent knowledge of the system and to describe the relationships between parts of the system. Ontology enables the sharing of structured information among people or software agents. [14].

4.2.1 Unified Modeling Language

The UML is a standardized tool developed by the organization Object Management Group, for visual modelling. The objective is to "provide system architects, software engineers, and software developers with tools for analysis, design, and implementation of software-based systems as well as for modeling business and similar processes". [15]
The UML diagrams can be divided into two groups:

- structure diagrams or static diagram
- behavioral diagrams or dynamic diagrams.

The structure diagrams are used to analyze the structure of the mapped system by identifying the objects, attributes, and relationships within the system. Typical examples of the structure diagrams are class diagrams, and component diagrams. On the other hand, the diagrams for

mapping the behavior of the system are called behavioral diagrams. They are implemented when there is a need for identifying the collaboration of the system with other entities, as well as the internal and external components of the system. The typical examples are use case diagrams, activity diagrams, state machine diagrams and sequence diagrams. [15]
The remaining parts of this subsection describes and explains the syntax of the UML diagrams. Moreover, the software tool Enterprise Architect used for modeling the UML diagrams is described in Section 4.2.1.

Use Case Diagram

The Use Case Diagram is a tool for setting the scope of the system, defining, and organizing the function/service/process of the system. A Use Case Diagram describes the interaction between a function/service/process and its external users. A Use Case Diagram consists of three main components, that are shown in Figure 4.1. These three components are – Actor, Boundary and Use Case.

- **Actor** – An external user who interacts with the system is called Actor. An Actor is represented in a Use Case Diagrams by a person.
- **Boundary** – The system is always bounded by a rectangle.
- **Use Case** – A horizontally shaped ovals represent a Use Case. The Use Case is a function/service/process provided by the system to the Actor. A system's Boundary encloses one or multiple Use Cases.

The interactions between the Actors and Use Cases are represented by relationships. The relationships are depicted by a line connecting an Actor and a Use case, and between two

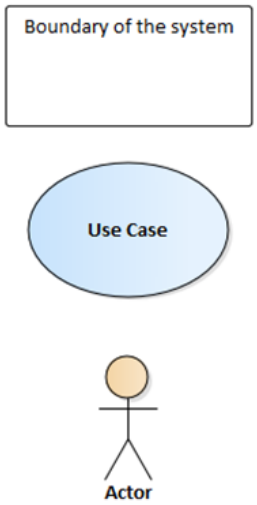


Figure 4.1: Main components of the system: Boundary of the system, Use case, Actor

Use Cases in a Use Case Diagram. Three general types of relationships, namely Association, Extend, and Include, are shown in Figure 4.2.

- **Association** – Association is represented by a solid line without an arrow. An Association describes a general two-way interaction between an Actor and a Use Case. In case there is an Association between an Actor and a Use Case, the action of the Actor is required to complete the Use Case. If there are two Actors associated to one Use Case, participation of both Actors is required to complete the Use Case.

- **Extend** – Extend is represented by a dotted line with an open arrow and the text «extend». Extend is used to describe an interaction between two Use Cases, where the function/service/process of the Use Case at the upstream end of the arrow is extended to the Use Case at the downstream end of the arrow. However, the completion of the extended Use Case is optional.

- **Include** – Include is represented by a dashed line with an open arrow and the text

«include». This type of line is used between two Use Cases. Include is used when the Use Case (at the upstream end of the arrow) requires the Use Case at the downstream end of the arrow to be completed.

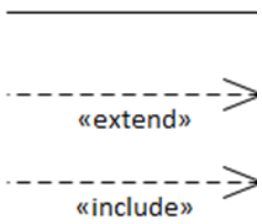


Figure 4.2: Relationships of the system: Association, Extend, Include

Moreover, there is also a type of relationship between two or more Actors. The relationship called Generalization is used to describe an Actor inheriting all properties of another Actor. The relationship is represented by a solid line with a closed arrow. The Actor at the upstream end of the arrow inherits all the properties of Actor at the downstream end of the arrow. On the other hand, the generalized Actor does not inherit the properties of the Actor in the opposite direction of the arrow. Generalization is shown on the Figure . Figure shows a simple example: the Actor named Traveler is the Generalization of the Actor named Pedestrian and the Actor named Driver. The Pedestrian and the Driver inherit all properties of the Traveler.

Activity diagram

The Activity diagram is used to graphically represent the workflow that may occur within the system. The workflow is described as a sequence of steps that define the life cycle of the process. There are seven components of the diagram: Initial State, Actions, Decisions, Control Flow, Fork, Join and Final State. These are shown in Figure 4.4.

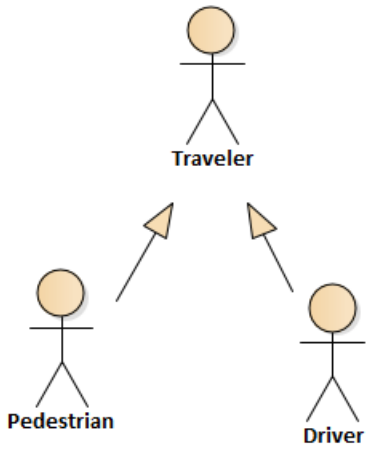


Figure 4.3: Generalization - example using Traveler, Pedestrian, and Driver

- **Initial State** – The Initial State represents the beginning of the workflow by a full black circle.

- **Action** – An Action is a process within the workflow that is represented by a rectangle with round corners containing the name of the process.

- **Decision** - A decision is represented by a diamond with an attached question that has multiple answers. The most common answers are yes or no. Each answer points to a Control Flow that leads to the next step.

- **Control Flow** – A Control Flow is a solid line with an open arrow marking the flow of the process. The arrow always points from the upstream activity (Initial State, Action, Decision, Fork, Join or Final State) to the downstream activity. Moreover, when pointing out from a Decision node, the Control Flow arrow can also include text representing the answers that can occur within the decision.

- **Fork** – Forks are used together with Joins when mapping parallel workflows. The

parallel workflows diverge from a Fork, which is represented by a thick solid vertical or horizontal line. The Fork generates a certain number of tokens based on the number of parallel Control Flows (arrows) pointing out from the Fork. The Fork sends a token to each of the parallel workflows.

- **Join** – Joins are used to merge parallel workflows. A Join is represented by a thick solid vertical or horizontal line. A Join collects the tokens that were sent to the parallel Control Flows by the Fork upstream. To continue to the following activity after the Join, it is necessary that all of the tokens that were sent by the Fork are collected by the Join.

- **Final State** – The final state is used to mark the end of the workflow, and it is represented by a hollow circle with an inner full circle.

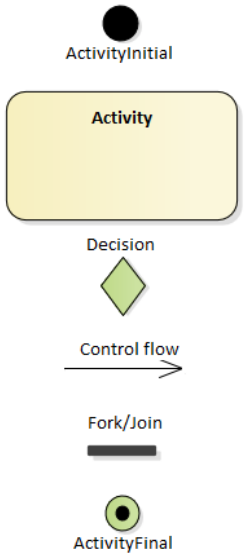


Figure 4.4: Components of the Activity diagram: Initial State, Activity, Decision, Join/Fork, Final State

Enterprise Architect

Enterprise Architect is a commercial software tool developed by Sparx Systems. It is used to model UML diagrams. According Sparx Systems, the Enterprise Architect "provides solution to visualise, analyse, model, test and maintain all of systems, software, processes and architectures [16].

The figure 4.5 shows a screenshot of the software. The section Project Browser shows the hierarchy of the diagrams in the open project. Next to the Project Browser, there is a section Toolbox, this section provides set of tools based on the type of the diagram. The diagrams can be created by placing the tools from the toolbox section into the workplace located in the middle of the screen. On the right side of the screenshot, there is section called Diagram Properties, that provides description of selected object of the diagram.

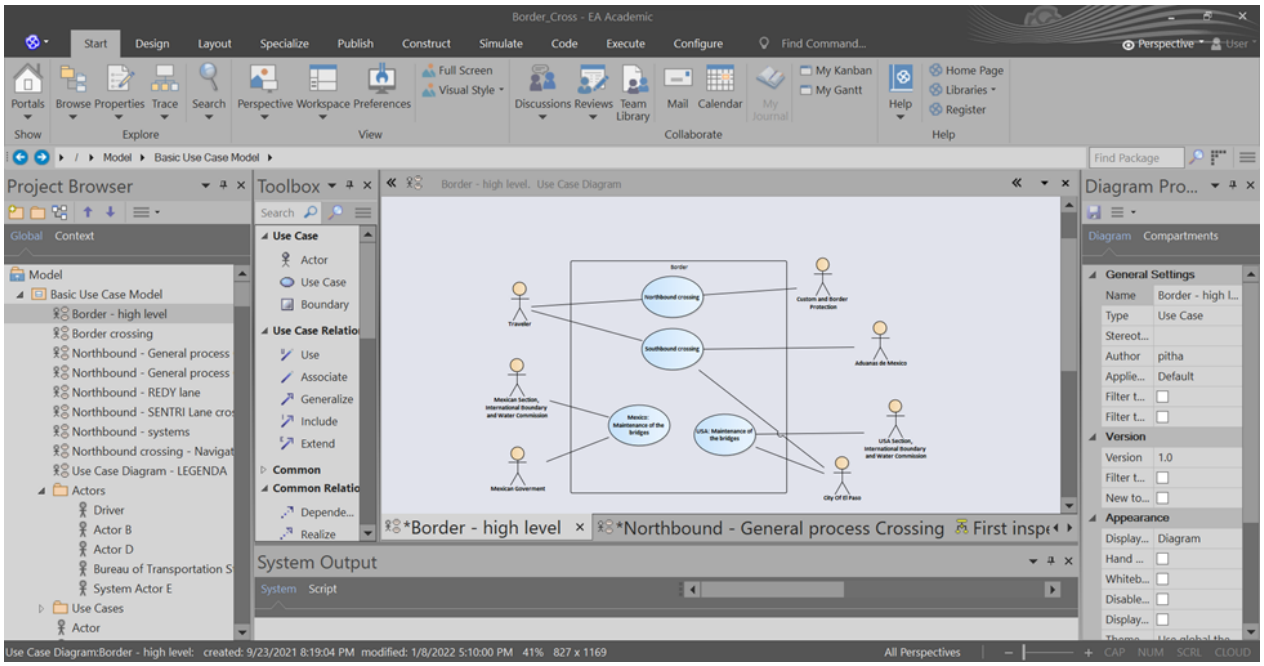


Figure 4.5: Screenshot of GUI of Enterprise Architect

4.2.2 Ontology

Ontology is defined as an explicit formal specifications of the terms in a domain and relations among them [14]. In other words, is used for describing certain knowledge of a system in a machine-readable way based on linking data within a web. The main benefit of using ontology is connecting the information within a web for sharing a common understanding of the domain. Ontology play important role in areas like machine learning, semantic web, artificial intelligence, or system engineering.

There are multiple ontology languages that enables different functionalities. The most commonly used are Resource Descriptive Framework (RDF) and Web Ontology Language (OWL). Moreover, the graphical representation of the ontology design is called Concept Map. RDF belongs to the group of the most basic ontology languages. RDF was developed by the World Wide Web Consortium in 1990's. RDF is used to define the classes, subclass, its individuals and relations between them [17]. Moreover, the hierarchy among these classes can be stated. This ontology language is frequently used for data interchange on the web.

The main components of RDF are semantic triple. They are used to codify statements about data. The components of semantic triple are:

- Subject
- Predicate
- Object

Subject and Object are objects within the web (can be classes or individuals). Each Subject or Object is graphically represented by an oval. A Predicate defines the relation between a

Subject and an Object. A Predicate is graphically represented by a line with arrow pointing from the Subject to the Object.

Figure 4.6: Components of ontology: subject, predicate, object

In RDF the statements are defined using Extensible Markup Language (XML), since the ontology is meant for web purposes elements are defined by URI. For this reason, namespaces can be used to shorten the URI. The structure of namespace is defined as: *xmlns:prefix="URI"* [18]. In one ontology design, multiple existing ontologies can be used to link the available resources. When using other ontologies,it is important to define its namespaces in the beginning of the RFD document.

The second important ontology language is Web Ontology Language (OWL). OWL provides definitions of local restrictions, negations, distinctions withing a class, or class conditions [17]. OWL projects can leverage the RDF design, and the most commonly used software is called Protege.

5. The Border Crossing System

5.1 Taxonomy of Identified Services

The chapter provides descriptions of the Border Crossing System using the UML diagrams discussed in Chapter 4. The Border Crossing System is initially described from the high level point of view. Then, selected services of the systems, especially those related to the northbound crossing system, are mapped and described individually. Figure 5.1 describe the taxonomy of identified services. The numbers next to the services are the section numbers in this chapter. These are the services selected for discussions.

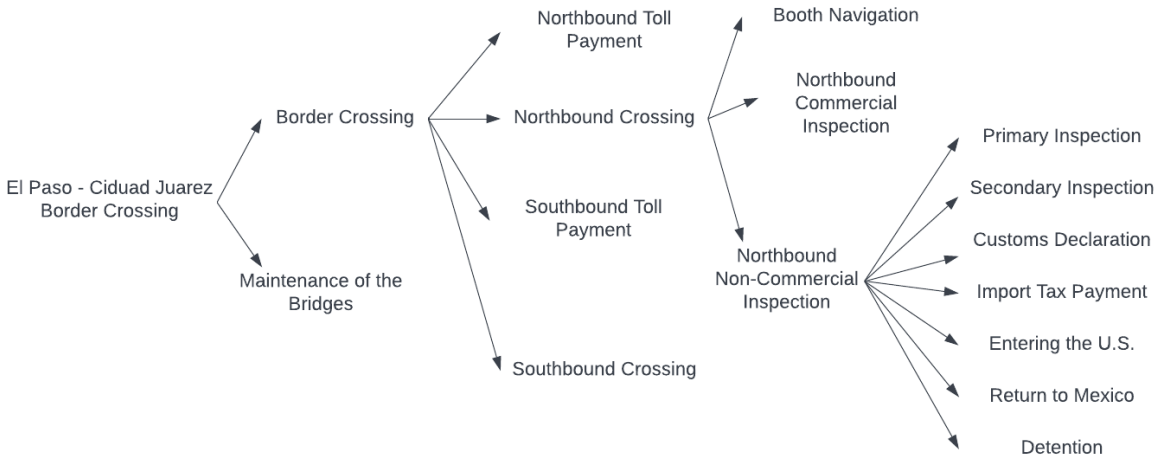


Figure 5.1: Taxonomy of Identified Services

5.2 El Paso - Ciudad Juarez Border Crossing

5.2.1 Use Cases of Border Crossing

This diagram in Figure 5.2 describes the El Paso Ports of Entry at the highest level. The system has only two functions, that cover the two main activities at the highest levels within the El Paso Ports of Entry system. The first function is Border Crossing and the second function is Maintenance of the Bridge.

The Border Crossing function describes all the activities related to crossing the border either in the northbound direction (from Mexico to the U.S.) or the southbound direction (from the U.S. to Mexico). The actors related to these use cases are: Traveler - which is a generalization of the travelers of all modes; Operator - which is a generalization of the officers of border protection agencies (Aduanas de Mexico and the U.S. Customs and Border Protection or CBP); and Toll Organization - which is the generalization of the City of El Paso and Fideicomiso de Puentes Fronterizos de Chihuahua. The Border Crossing use case is described in Section 5.2.3.

The Maintenance of the Bridge infrastructure is the second function. Multiple agencies are responsible for the state of the bridges. Moreover, since the bridge has two sides - the Mexican and the U.S. sides, there is an organization responsible of each side of the bridge. In this diagram, the collection of the responsible organizations are represented by the actor named Maintaining Organization. The Maintenance of the Bridge use case is described in Section 5.2.2.

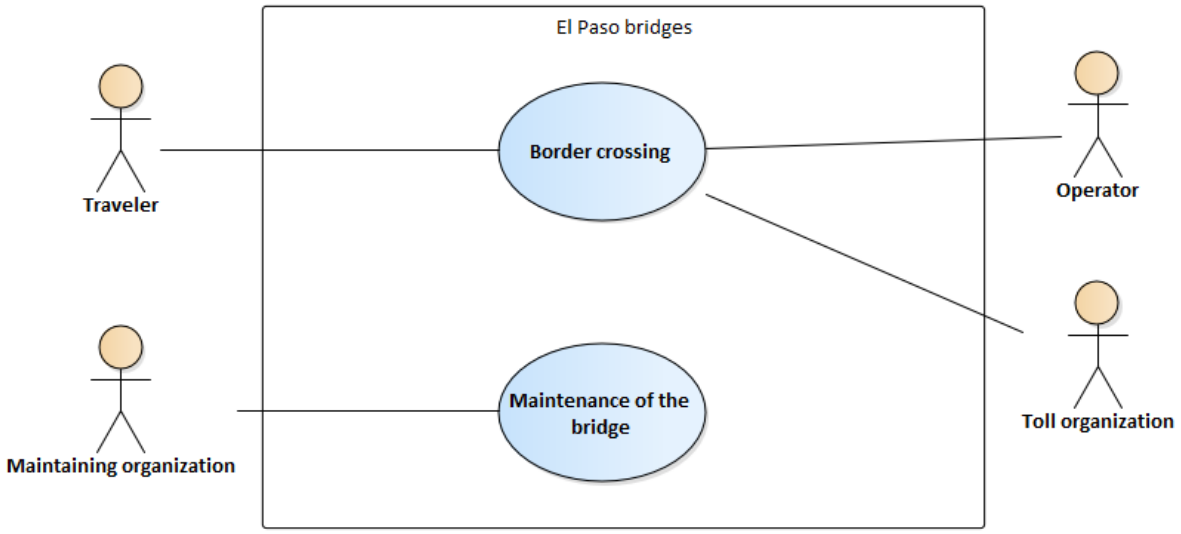


Figure 5.2: Architecture diagram – El Paso Ports of Entry

5.2.2 Use Case: Maintenance of the Bridges

The use case diagram in Figure 5.3 maps the organizations responsible for maintaining the infrastructure of the bridges. The maintenance of each bridge involves the interactions between two actors. They are the organizations responsible only for the part of the bridge that lies in their respective jurisdictions.

The use cases named Ysleta Bridge Maintenance, Paso del Norte Bridge Maintenance, and Stanton Bridge Maintenance each involves two actors: the City of El Paso - that maintains the U.S. part of the bridge, and the Government agency of Mexico - that maintain the Mexican part [2]. The BOTA is maintained by the U.S. Section of the IBWC and Mexican Section of the IBWC. [2].

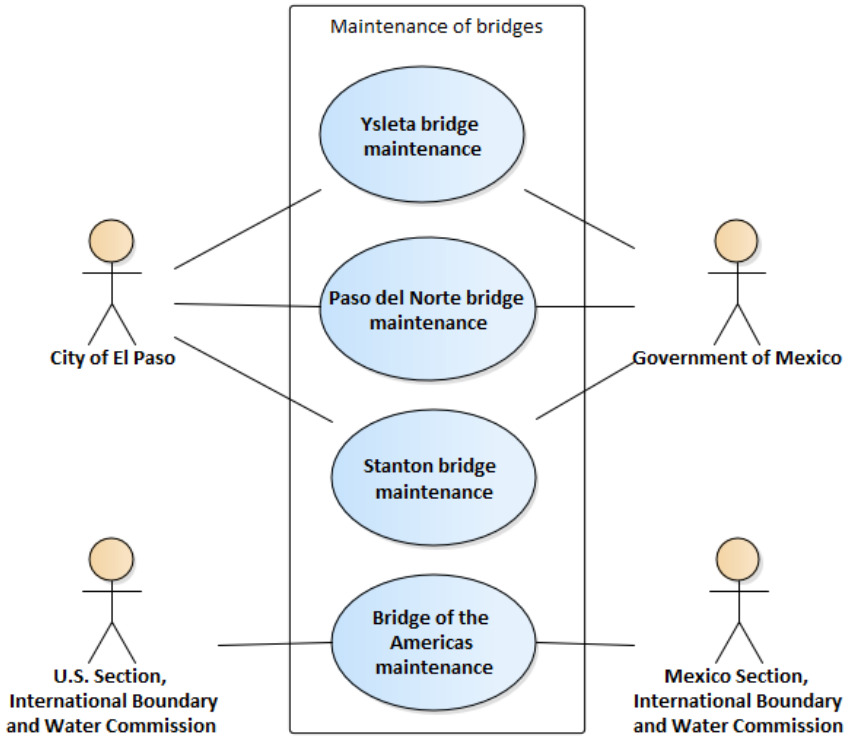


Figure 5.3: Use case diagram – Maintenance of the Bridge

5.2.3 Use Case: Non-Commercial Border Crossing

Figure 5.4 shows the four main functions or services that are part of the Border Crossing use case.

Northbound: Crossing - covers the process of crossinf from Ciudad Juarez to El Paso. The Traveler interacts with CBP Officers for immigration and customs inspections before entering the U.S. from Mexico.

Northbound: Toll Payment - represents the toll payment on the Mexican side of the border. The Traveler pays toll to Fideicomiso de Puentes Fronterizos de Chihuahua.

Southbound: Crossing - covers the border crossing process when crossing from El Paso to Cidad Juarez. The traveler interacts with Aduanas de Mexico Officer.

Southbound: Toll Payment - represents the toll payment when entering the brisge in El Paso. The Traveler pays toll to the City of El Paso.

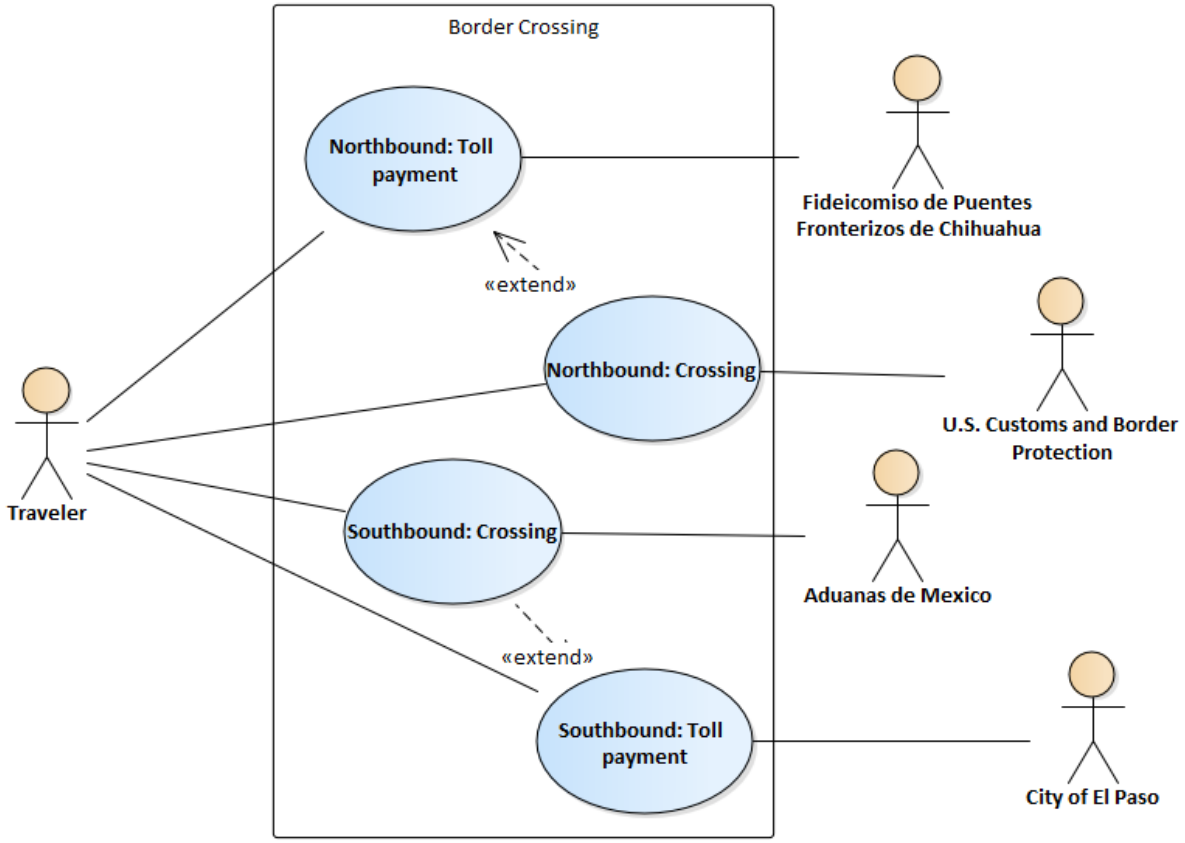


Figure 5.4: Use case diagram – Border Crossing

5.2.4 Use case: Northbound Crossing

The Northbound: Crossing use case covers the process of entering the U.S. from Mexico. It consists three use cases, namely Booth Navigation, Non-Commercial Border Crossing Inspection and Commercial Border Crossing Inspection. Booth Navigation directs a Traveler to the appropriate inspection booth depending on his/her mode of travel (pedestrian, passenger vehicle, commercial vehicle) and status (e.g., SENTRI membershp, RFID passport).

Non-commercial Border Crossing Inspection covers the inspections of pedestrian, travelers in passenger vehicles, and their passenger vehicles. Commercial Border Crossing Inspection covers the inspections of the travelers (drivers) inside the commercial vehicles, the commercial vehicles and the contents.

There are two types of Traveler: Non-Commercial Traveler and Commercial Traveler. Non-Commercial Traveler are pedestrian are those who cross in passenger vehicles. Commercial Traveler refers to drivers or passengers inside commercial vehicles. Both are generalized into Traveler.

A Non-Commercial Traveler interacts with CBP Officers during the Non-Commercial Border Crossing Inspection process. A Commercial Traveler interacts with CBP Officers during the Commercial Border Crossing Inspection process. The Booth Navigation process only impacts Traveler.

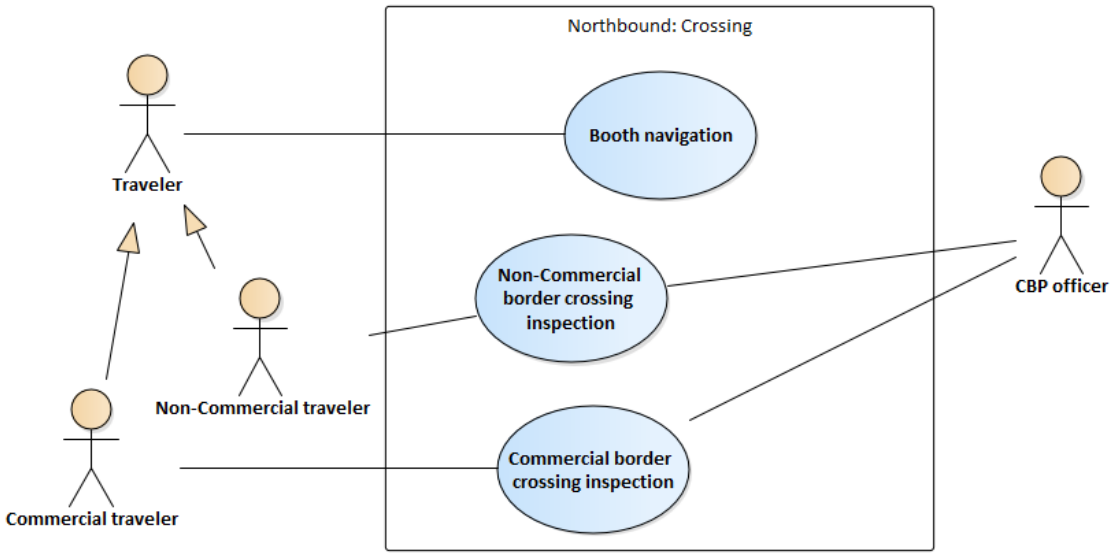


Figure 5.5: Use case diagram – Northbound: Crossing

5.2.5 Use Case: Booth Navigation

Booth Navigation directs a Traveler to the appropriate inspection booth. There are several types of booth for each mode of travel, some with special requirements on the traveler. The Booth Navigation function is implemented by displaying the types of booth in electronic variable message signs placed above the bridge approach well as above each booth.

In the Booth Navigation use case (see Figure 5.4), the actor Traveler is the generalization of all travelers. The actor Non-Commercial Traveler is a generalization of Pedestrian and Passenger Vehicle Occupant.

There are seven types of inspection booths. Each type of inspection booth functions to serve a particular type of traveler.

The General Crossing process serves all travelers (actor Traveler).

The FAST Lane Crossing process serves Commercial Travelers who paid a FAST membership or Commercial Traveler who is a member of the C-TPAT program.

The SENTRI Lane Crossing process serves Non-Commercial Traveler (including Passenger Vehicle Occupant and Pedestrian) who is a member of the SENTRI program.

The SENTRI Lane Crossing process serves Non-Commercial Traveler (including Passenger Vehicle Occupant and Pedestrian) who travels with a RFID readable passport.

Three types of booth process serve only Pedestrians. The Bus Crossing cover process of a Traveler who boards a bus in Ciudad Juárez, alights the bus before the Inspection Booth and boards the bus again after the inspection. The Student Crossing process is set aside to speed up process of students (F-1 visa holders), who cross the border on regular basis. Special Assistance Crossing is a for the disabled.

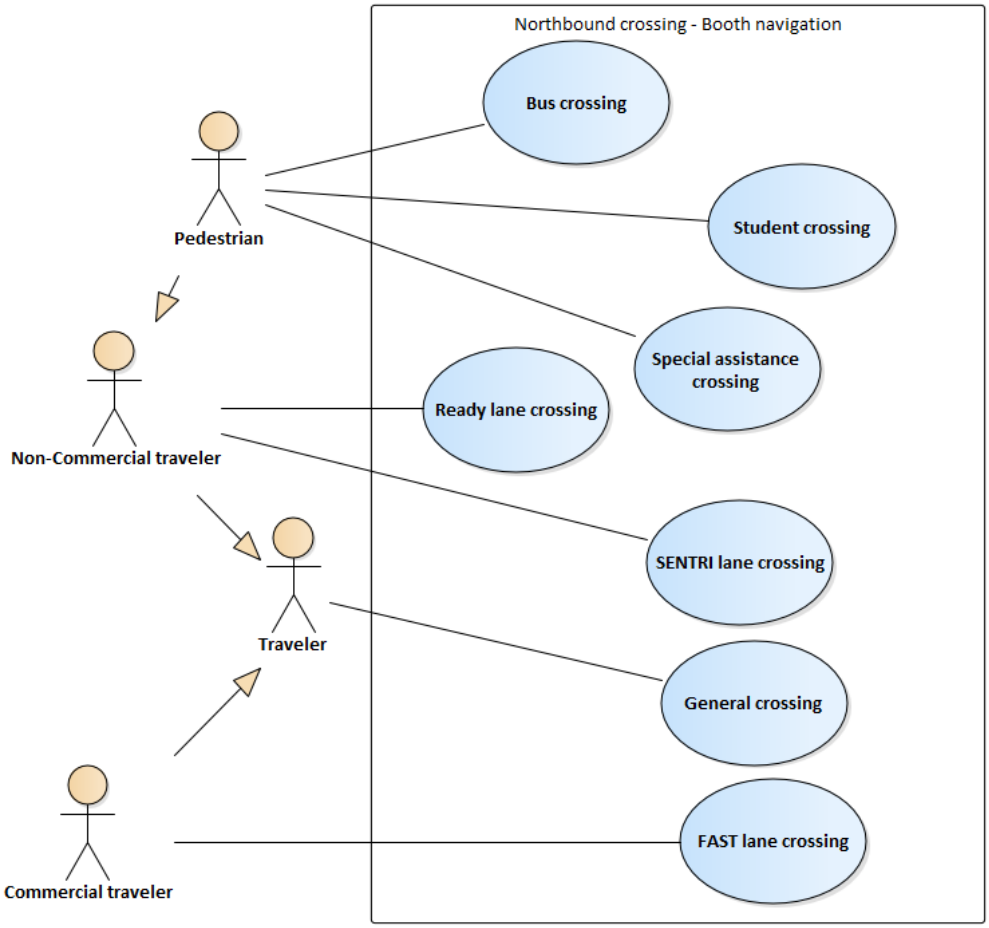


Figure 5.6: Use case diagram – Booth Navigation

5.2.6 Use Case: Northbound Non-Commercial Inspection

The use case of Border Crossing Inspection is shown in Figure 5.7. The Border Crossing Inspection has six functions or processes.

The main and first function is the Primary Inspection where the Non-Commercial Traveler interacts with a CBP officer. The Primary Inspection may extend to the following five services. The flow chart of the Primary Inspection process is described in the chapter 5.3.2. The Secondary Inspection is an extension of the Primary Inspection. Customs Declaration is an extension of the Primary Inspection or Secondary Inspection. Paying Import Tax is

an extension of the Primary Inspection, Secondary Inspection or Customs Declaration. The Return to Mexico and Entering the U.S. processes represent the are extensions of the Primary inspection and the Secondary inspection. Lastly, the Detention process is an extension of the Secondary Inspection, if there is serious issue identified.

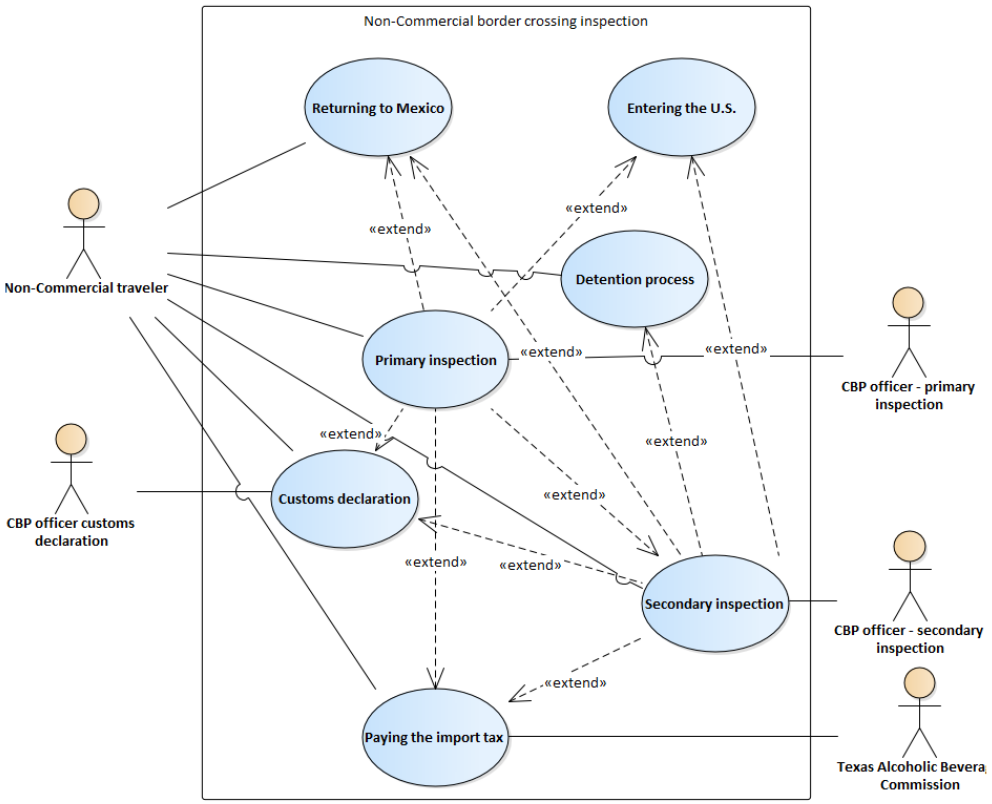


Figure 5.7: Use case diagram – Border Crossing Inspection

5.3 Northbound Non-Commercial Crossing Process

5.3.1 Workflow

The section describes the activity of the non-commercial northbound crossing. The process starts with paying toll to the Fideicomiso de Puentes Fronterizos de Chihuahua. Tolls are

collected at the Stanton, PDN and Ysleta POEs. The is no toll for crossing at the BOTA POE. When crossing by a passenger vehicle the toll is paid to an officer in a booth. The toll for a pedestrian is paid at a turnstile. After paying toll, the crossing process continues with booth navigation, where the traveler approaches an inspection booth that matches his/her travel documents and status. During the booth navigation process, a pedestrian may be subjected to a document pre-check, where a CBP officer verifies that the traveler has the required documents. At the booth, the traveler is subjected to a primary inspection. The primary inspection is when a CBP officer checks the documents and ask questions to determine the eligibility of the traveler to enter the U.S. If there is need for an additional verification, a secondary inspection (which consists of a more detailed document check and interview) is followed. After the primary or secondary inspection, if the traveler is allowed to enter the U.S., he/she continues with the customs inspection. For pedestrian, the customs inspection is performed by using an X-ray machine to scan the bag. Travelers in a passenger vehicle may be asked by a CBP officer to open the trunk for manual inspection of the contents. If a traveler makes a customs declaration, or asked by a CBP officer to pay import tax, the traveler proceeds to pay the import tax. Depending on the type of imported goods, the tax will be paid at a CBP customs booth or a Texas Alcoholic Beverage Commission booth, or both.

The flowchart of northbound non-commercial crossing process for passenger vehicles is shown in Figure 5.8. The process for pedestrian is shown in Figure 5.9. The processes of primary inspection, secondary inspection and customs declaration are described in Sections 5.3.2, 5.3.3, and 5.3.4 respectively.

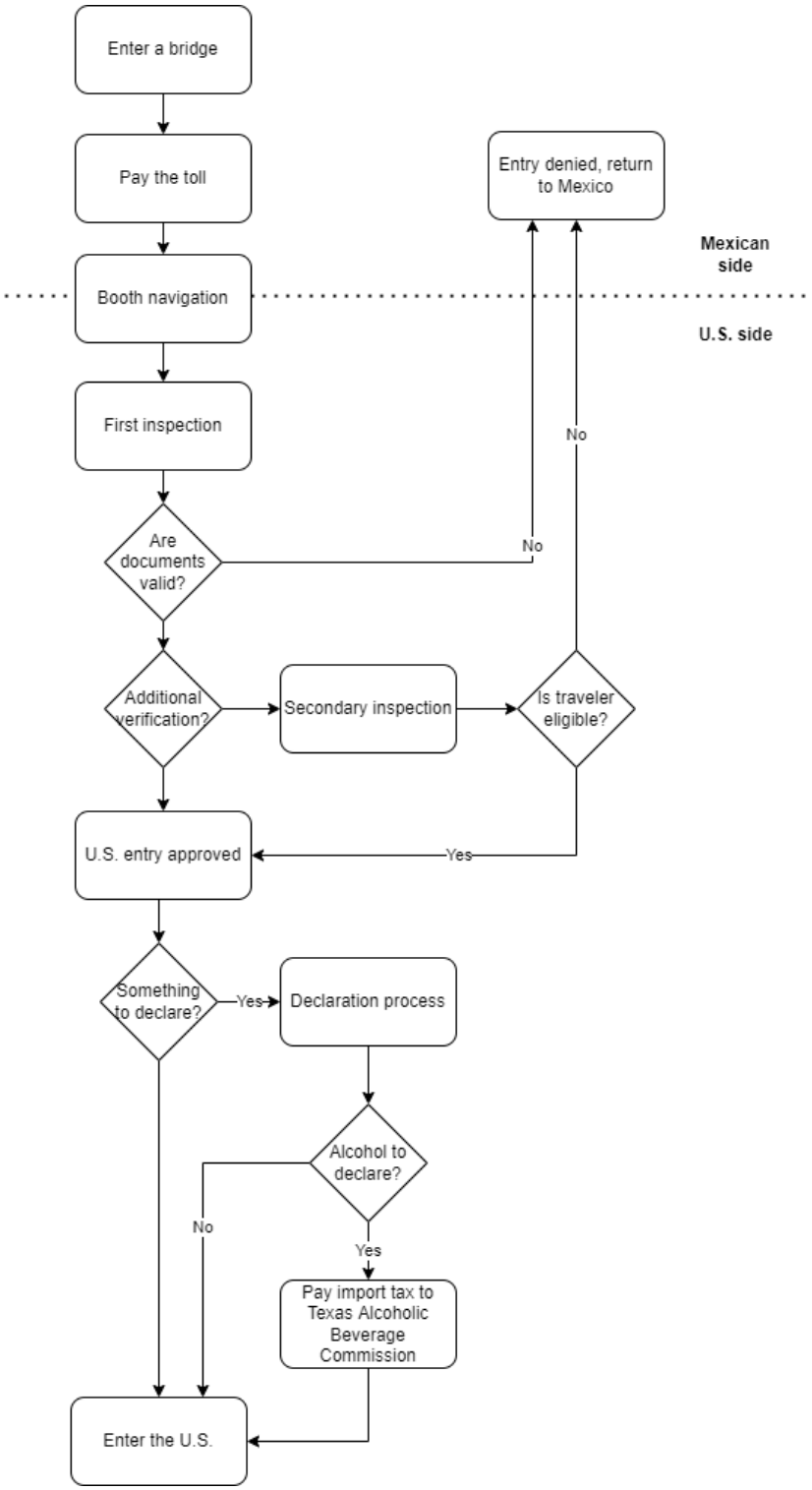


Figure 5.8: Flowchart of northbound vehicle crossing process

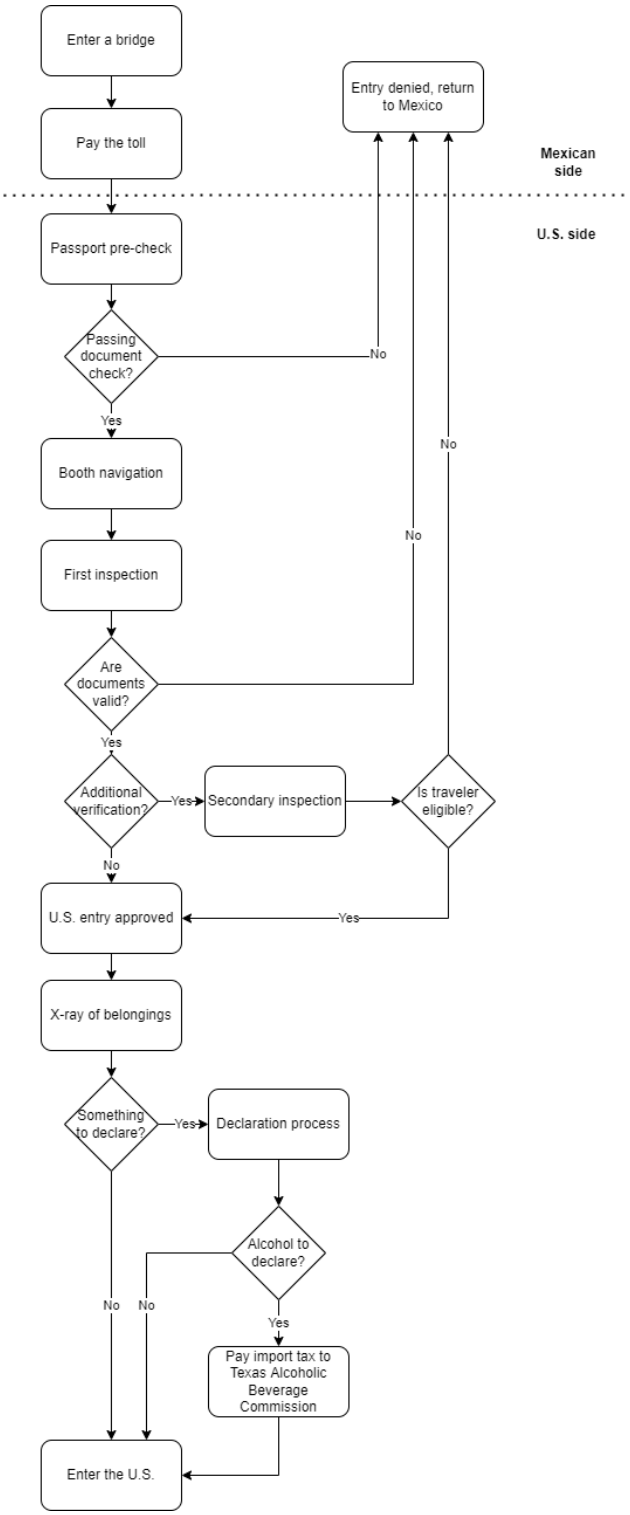


Figure 5.9: Flowchart of northbound pedestrian crossing process

5.3.2 Activity: Non-Commercial Northbound Inspection

The border crossing inspection is a systematic process established by the CBP to determine the eligibility of an arriving international traveler or a returning U.S. citizens to enter the U.S. The inspection process including all its possible scenarios is shown in Figure 5.10. For the inspection, each traveler must provide documents such as passport, visa, and other supporting evidence to a CBP officer to confirm his/her identity, nationality, and the purpose of the travel. Additionally, biographic and bio-metric data could be collected.

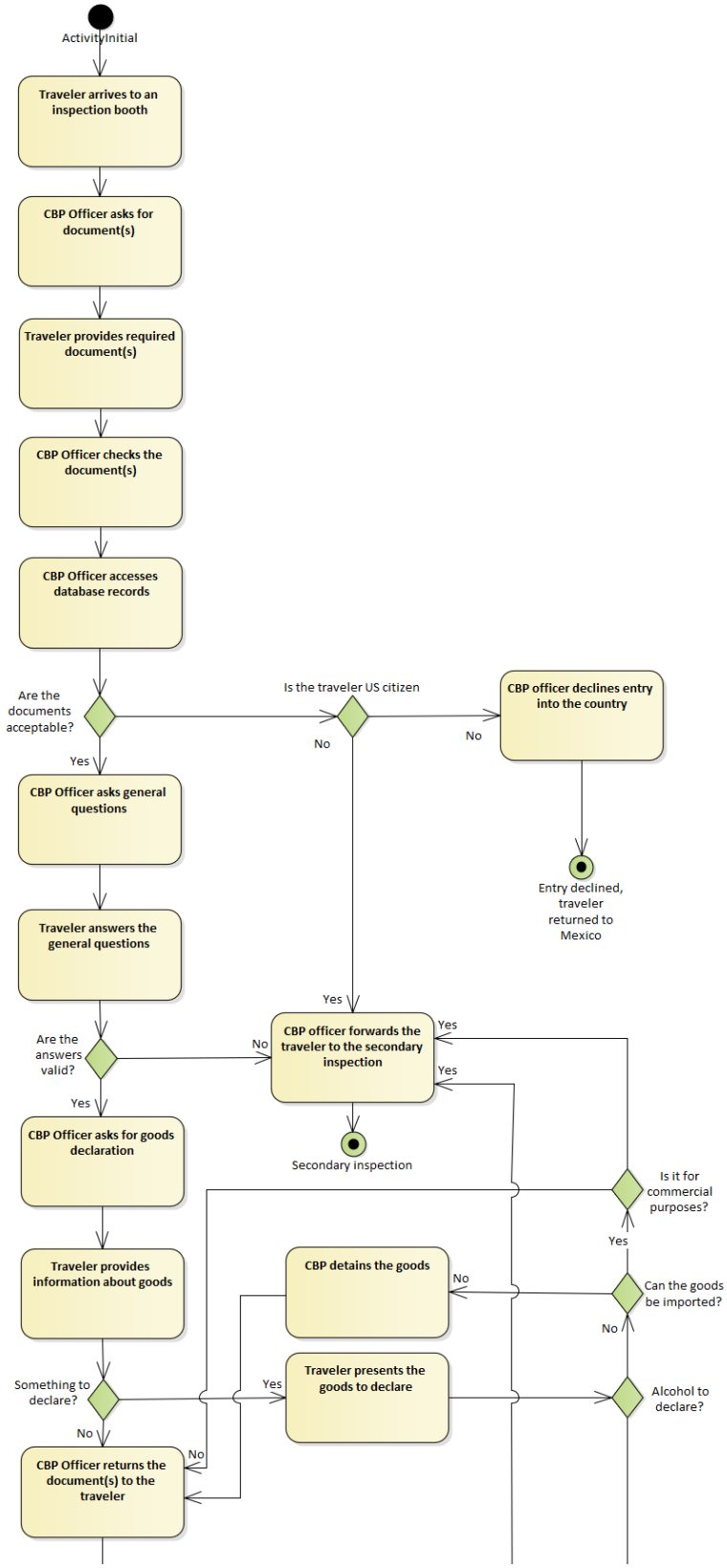
If the international traveler fails to provide sufficient documents to the CBP officer, the entry into the U.S. is denied, and traveler is asked to return to Mexico. A U.S. citizen cannot be denied from entering his/her home country. A U.S. citizen without the required documents is usually forwarded to the secondary inspection.

As part of the primary inspection, a CBP officer asks the traveler general questions about the trip. If there is any issue with the documents or with the answers provided, the CBP officer directs the traveler to the secondary inspection. The secondary inspection performs more detailed inspection to determine admissibility. The scenario of the secondary inspection is described in the chapter 5.3.3.

The inspection continues with the questions regarding goods declaration. In there is something to declare, the traveler has to present the goods to the CBP officer. The CBP officer determines if tax should be collected. If the imported goods is alcohol, the CBP officer returns the documents to the traveler, and the traveler proceeds to the booth of Texas Alcoholic Beverage Commission to pay the import tax. If the goods cannot be imported to the U.S., the CBP officer detains the goods and the inspection can continue in the standard way.

In case the imported goods is for commercial purposes, the traveler is sent to a secondary inspection booth, where another CBP officer to estimates the value of the goods and decides the import tax.

After the declaring goods and paying tax (if any), the standard process of the the north-bound non-commercial inspection is completed. At this point the CBP officer returns all the documents to the traveler, who is approved to enter the country. Finally, in case the traveler is a pedestrian, there is an additional step of X-ray of the belongings. In case there is any goods identified, the process is very similar to the goods declaration during the inspection, out of the fact, that traveler has to pay a penalty fee.


Activity Initial
Traveler arrives to an inspection booth
CBP Officer asks for document(s)
Traveler provides required document(s)
CBP Officer checks the document(s)
CBP Officer accesses database records
Are the documents acceptable?
Is the traveler US citizen
CBP officer declines entry into the country
No
No
Yes
Entry declined, traveler returned to Mexico
CBP Officer asks general questions
Traveler answers the general questions
Yes
Are the answers valid?
No
CBP officer forwards the traveler to the secondary inspection
Yes
Yes
Yes
Secondary inspection
CBP Officer asks for goods declaration
Is it for commercial purposes?
Yes
Traveler provides information about goods
CBP detains the goods
No
Can the goods be imported?
No
Something to declare?
Yes
Traveler presents the goods to declare
Alcohol to declare?
No
CBP Officer returns the document(s) to the traveler
No

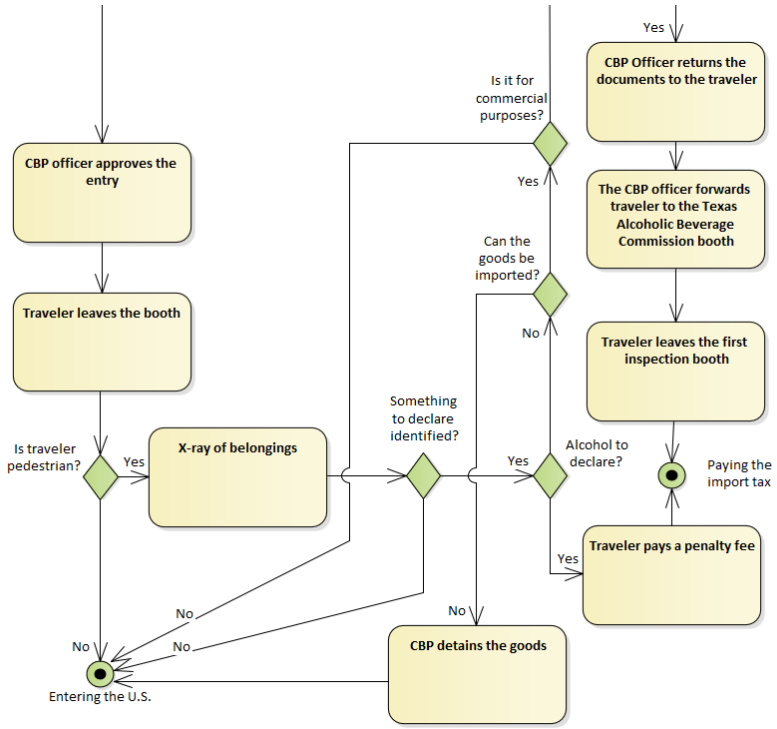


Figure 5.10: Activity diagram - non-commercial northbound inspection

I-94 Permission

The Form I-94 is proof of legal entry into the United States. According to the US Customs and Border Protection it us "needed by all visitors except: U.S. Citizens, returning resident aliens, aliens with immigrant visas, and most Canadian citizens visiting or in transit" [19]. The process of getting I-94 is in case of arriving by sea or air processed automatically, but for arriving by land, the travelers who don't have I-94 need to apply for it. The application process is based on filling an online form and processing an interview including collecting records. It has to be processed before the traveler enters the primary inspection. After completing the online form traveler arrives to a special booth located in front of the primary inspection booth to complete the process with CBP officer. After the process of applying

for new I-94 is completed, a CBP officer attaches the I-94 form into the traveler's passport. Traveler who already have I-94 form don't need to apply for it, and their I-94 is updated automatically during the primary inspection.

5.3.3 Secondary Inspection

Secondary inspection is an additional step of the border crossing inspection, which is applied in case of random selection as well as when it is necessary to ask more questions, verify information, or to check the properties to determine admissibility without slowing down the traffic. The inspection process including all possible scenarios is mapped on the figure 5.11. Everyone including the U.S. citizens might be sent to a secondary inspection.

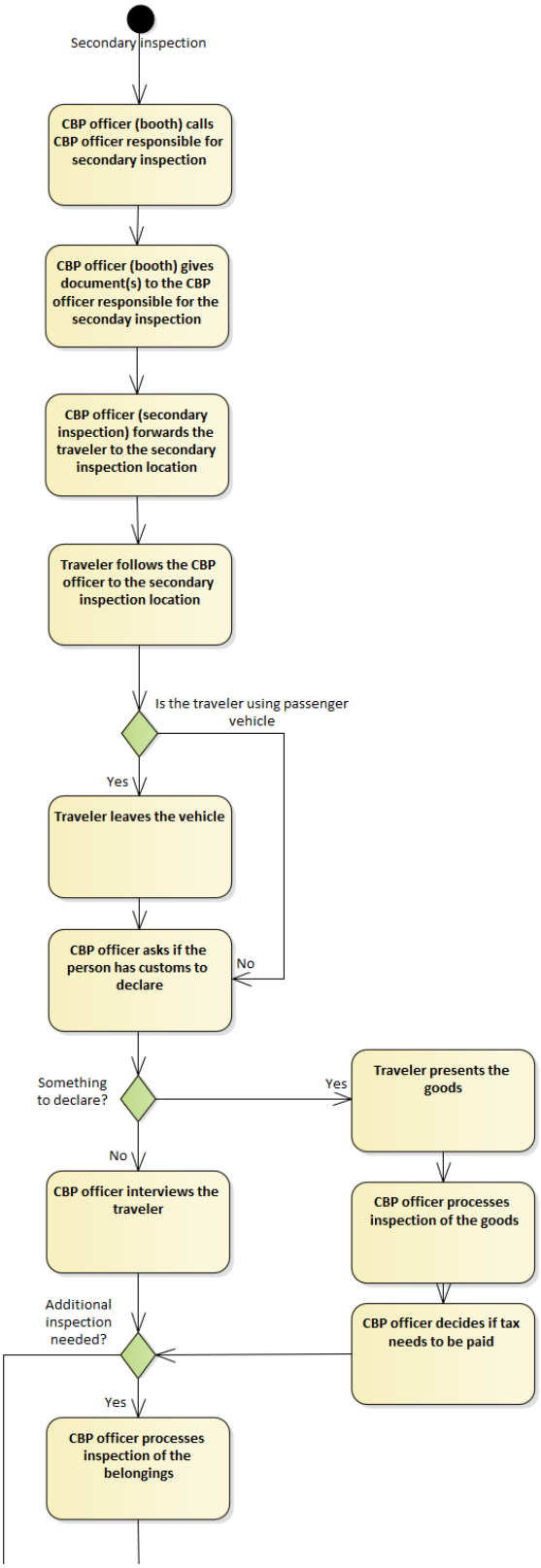
The inspection is processed on a different place than the general booth. During the secondary inspection, person is asked detailed open-ended questions, to proof the identification, determine the purpose of travel, or immigration history of the person. The process also covers a detail search of the belongings, that might also include the search of all electronic information. The process is generally very complex and comprehensive, and it can, based on the situation, take several hours to complete.

The process starts with forwarding all the documents of the traveler to the CBP officer that is responsible for secondary inspection, and navigating the traveler to the special location dedicated for the secondary inspection. In case the traveler uses passenger vehicle, the traveler has to leave the vehicle.

Secondly, the CBP officer asks traveler if the something to declare. In case there is something to declare, the traveler presents the goods the CBP officer that decide whether there is need to pay the import tax.

Thirdly, the process continues with inspection of the belongings. In case the traveler is using passenger vehicle, the inspection of the vehicle is processed as well. Additional inspection might be required by the CBP officer in case there is any issue identified. The additional inspection requires traveler to drive to a location, where X-Ray inspection of the vehicle is processed. Based on the result of the X-Ray inspection, the CBP officer returns documents to the traveler, who is approved to leave the country, or the officer can detain the traveler for further processing.

Finally, after leaving the inspection booth, the traveler can be forwarded to a place to pay an import tax, in there was a need for it identifies during the secondary inspection. The customs declaration process is described in the chapter 5.3.4.


Secondary inspection
CBP officer (booth) calls CBP officer responsible for secondary inspection
CBP officer (booth) gives document(s) to the CBP officer responsible for the seconday inspection
CBP officer (secondary inspection) forwards the traveler to the secondary inspection location
Traveler follows the CBP officer to the secondary inspection location
Is the traveler using passenger vehicle
Yes
Traveler leaves the vehicle
No
CBP officer asks if the person has customs to declare
Something to declare?
Yes
Traveler presents the goods
CBP officer processes inspection of the goods
CBP officer decides if tax needs to be paid
No
CBP officer interviews the traveler
Additional inspection needed?
Yes
CBP officer processes inspection of the belongings

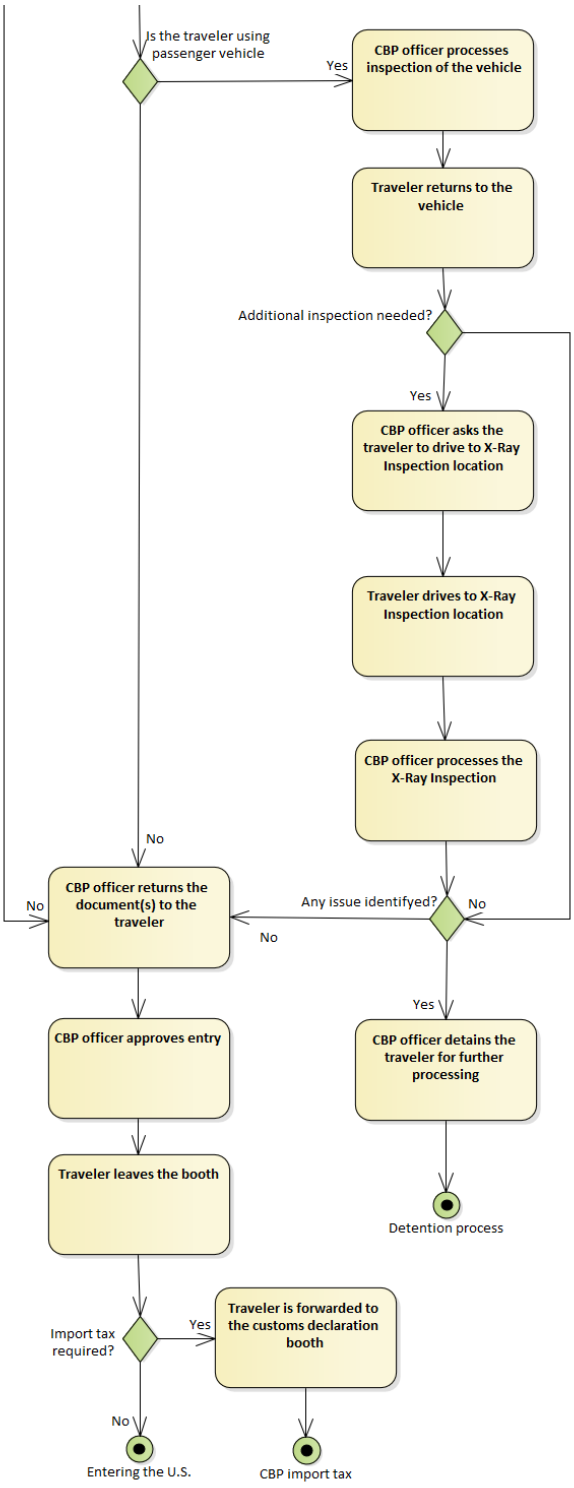


Figure 5.11: Activity diagram of the secondary inspection process

5.3.4 Customs declaration

Each traveler entering the follow a custom duty, that is according to the Custom and Border Protection defined as a tariff or tax imposed on goods when transported across international borders. The purpose of Customs Duty is according to the CBP "to protect each country's economy, residents, jobs, environment, etc., by controlling the flow of goods, especially restrictive and prohibited goods, into and out of the country"[20].

Traveler must provide a correct information about goods importing to the United States during the primary inspection, moreover the traveler must declare if the declared goods serve commercial purposes.

In case of importing alcohol the traveler is after the primary inspection forwarded to a special booth of Texas Alcoholic Beverages Commission to pay the import tax. In case other goods are imported, the traveler is forwarded to the secondary inspection for estimating the value of the imported goods. In case there is need to pay the import tax, traveler is forwarded to a special booth for paying the import tax.

5.4 Northbound Commercial Crossing

The process of commercial vehicle crossing is very different from passenger vehicle crossing. Commercial vehicles use different infrastructures than passenger vehicles. The process of commercial border crossing can be divided into three stages:

1. Pre-departure procedure

2. Aduanas inspection

3. CBP inspection

Firstly, the pre-departure procedure is processed by the private sector and it is based on preparing the shipment and processing the necessary documentation for Mexican as well as U.S. border inspection. The required documentations are called E-Manifest and Entry Summary, and they contain all information about driver and the shipment.

The primary inspection of commercial crossing starts when the vehicle is on the Mexican side. The officers of Aduanas process the export document check before the vehicle leaves Mexico. In there is any issue identified, the shipment is transported back to Mexico.

The inspection on the U.S. side is processed by the CBP officers. The process starts with measuring the weight of the vehicle and shipment by a weighing-in-motion device. A CBP officer checks if the measured weight is consistent with the registered vehicle class and declared shipment.

If there is no need for additional verification and there was no issue with the document, the shipment can enter the United States. If there is need for additional verification or inspection, the vehicle (with its shipment) is forwarded to a secondary inspection area. The secondary inspection covers various additional processes, depending on the issues identified by the CBP officer. The issues may be resolved by the CBP contacting the shipper to provide additional documents, and/or paying import tax before the shipment is allowed to enter the U.S.

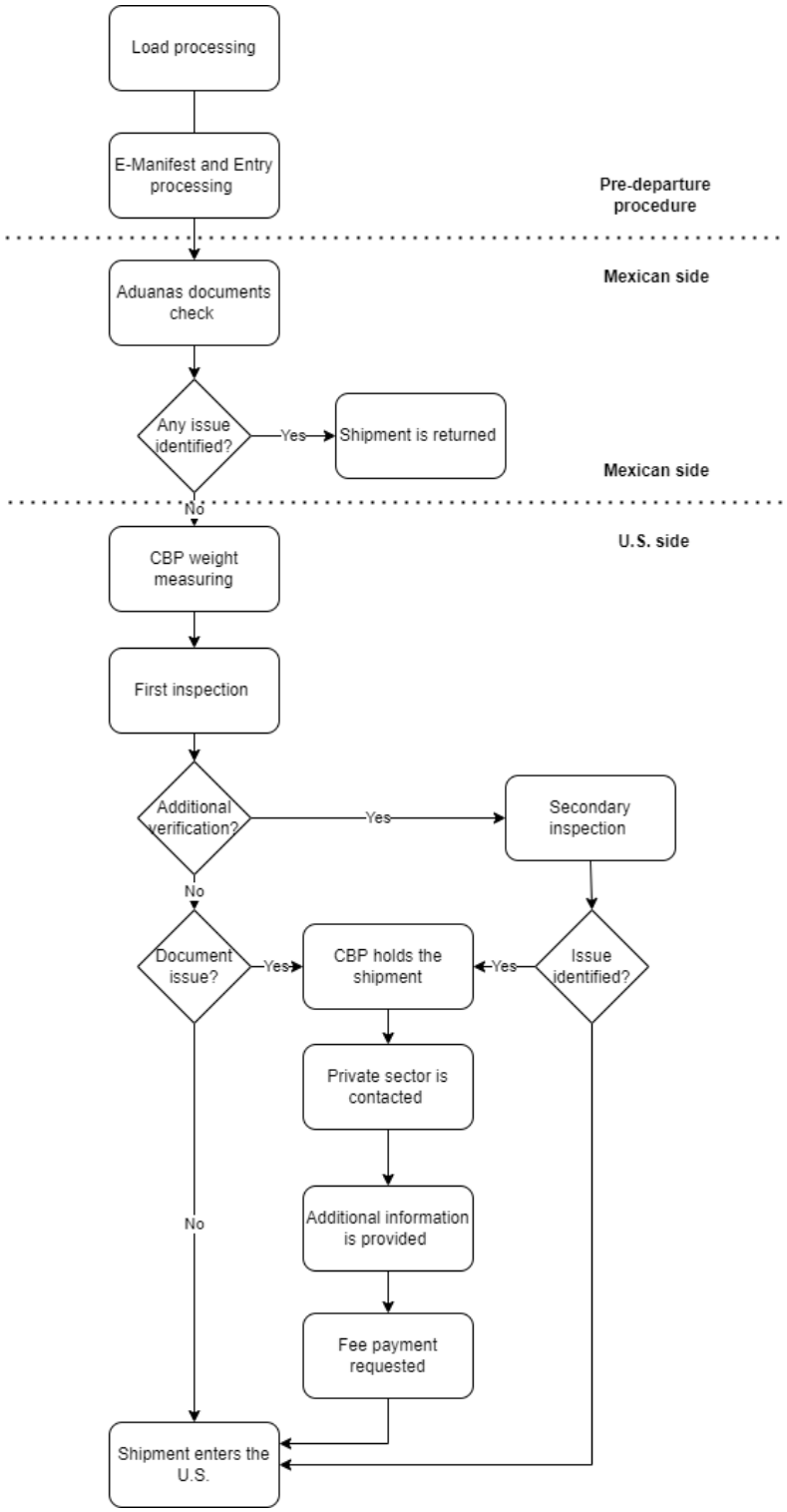


Figure 5.12: Flowchart of border crossing process of commercial vehicle

6. Ontology for Border Crossing

Based on the results in the Chapter 5 of the thesis, an ontology for border crossing was designed to represent the northbound border crossing system from Ciudad Juarez to El Paso in a machine understandable form. An earlier version of the ontology was designed in by a team of graduate students (including the author) for the UTEP course titled Special Topic in Data Science. It was modified by the author to meet the objective of this thesis.

The purpose of this ontology is to create a knowledge map of the northbound border crossing system at the land POEs between Ciudad Juarez and El Paso. It is important to mention that this ontology is not designed to answer all the possible queries. The purpose of this ontology is describe the basic knowledge so that it can be expanded by other designers to meet their particular needs.

An example of this extension could be including the information about the inspection time or border crossing times, together with information about Mexican and U.S. holidays or special events, and monitoring the effect of the events on the wait times. The ontology does not have to be restricted to the El Paso POEs. It can be applied to other border crossings on the U.S.-Mexican border.

6.0.1 Ontology Design

The ontology for border crossing may be divided into four parts: POE, traveler, lane and transportation mode.

The first part describes the POE infrastructures. The POEs are defined in the DBpedia ontology as dbp:Port of Entry[21]. There are three main subclasses of the class dbp:Port of Entry. The subclassses are:

- epj:SeaPOE - covering all POEs along the U.S. seaports.
- epj:AirPOE - covering all POEs at the U.S. airports.
- epj:LandPOE - covering all POEs at the land borders.

The class epj:landPOE contains two subclasses of POEs. Firstly, epj:USCanadaPOE covering the land POEs along the U.S.-Canada border. Secondly, the epj:USMexicoPOE covering the POEs along the U.S.-Mexico border. Under epj:USMexicoPOE, the POEs joining the City of El Paso and Ciudad Juárez are defined as a subclass named epj:EPJuarezPOE. This subclass has the following instances each represents a POE in the area:

- epj:BOTA - The Bridge of the Americas POE.
- epj:PDN - The Paso Del Norte POE.
- epj:Ysleta - The Ysleta POE.
- epj:Stanton - The Stanton POE.

The second part of the ontology describes the travelers. Travelers are identified in the DBpedia ontology as dbo:Person. For purposes of the thesis, there are two subclasses of dbo:Person:

- epj:CommercialTraveler - representing all commercial travelers.
- epj:NonCommercialTraveler - representing all non-commercial travelers.

The two instances of epj:CommercialTraveler are epj:FASTTraveler (for travelers with FAST memberships, including the members of C-TPAT) and epj:GeneralCommercialTraveler (representing general travelers without any membership as well as FAST travelers). The the non-commercial general traveler is represented as epj:GeneralNonCommercialTraveler,and it is type of the class epj:NonCommercialTraveler. Moreover, the class epj:NonCommercialTraveler has instances epj:RFIDTraveler (which represents travelers with any type of RFID-readable travel document), and epj:SENTRITraveler (which represents travelers with the SENTRI memberships).

The third part of the ontology describes the lanes. The highest class hierarchy of lanes is epj:Lane. It has four instances:

- epj:SENTRILane
- epj:ReadyLane
- epj:GeneralCommercial
- epj:GeneralNonCommercial
- epj:FASTLane

The class epj:Lane is connected to the class epj:EPJuarezPOE using the predicate epj:hasLane. The instances of classes epj:NonCommercialTravelers and epj:CommercialTravelers may be connected to instances of epj:Lane using the predicate epj:canUese.

The fourth part of the ontology describes the transportation modes, or more specifically the infrastructures that serve different transportation modes. Possible transportation modes that

can be used to cross the land border are put under the superclass epj:TransportMode. It has three instances:

- epj:CommercialVehicle - representing the infrastructure for commercial vehicle mode.
- epj:Pedestrian - representing the infrastructure for pedestrian mode.
- epj:PassengerVehicle - representing the infrastructure for passenger vehicle mode.

The predicate epj:hasMode describes that modes available at a POE. It may be used to connect an object (POE) that belongs to the class epj:ELJuarezPOE with subclasses of epj:TransportMode.

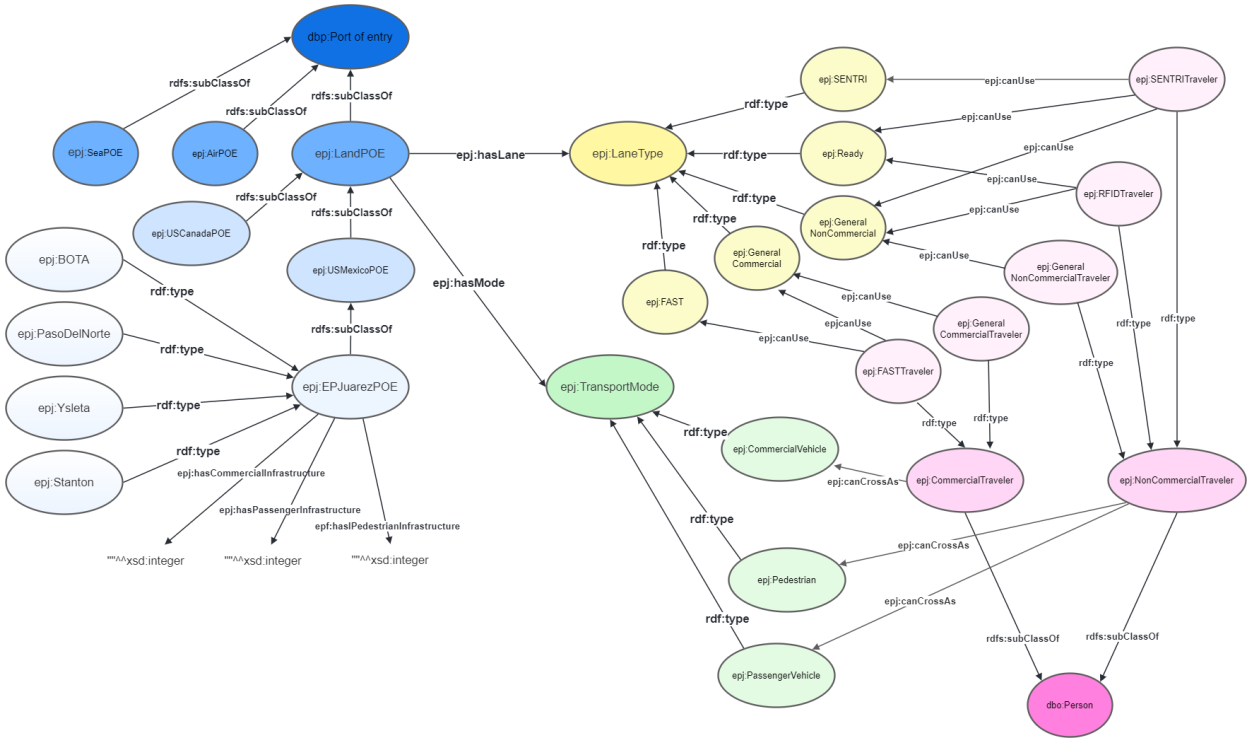


Figure 6.1: Conceptual schema of the ontology

6.0.2 Querying the Ontology

The main purpose of ontology is to represent certain knowledge in a machine readable form. The ontology model can be queried to discover the relationships between certain objects that are not obvious in the first sight. The rest of this section illustrates how the ontology may be used together with reasoning to respond to questions using SPARQL Protocol and RDF Query Language or simply SPARQL.

The ontology proposed in Figure 6.1 was tested with queries of the following forms:

1. Query 1: Is it possible to cross at Y POE by X mode?
2. Query 2: Which lane can a traveler of type Z use?
3. Query 3: What type of traveler can cross as in X mode?
4. Query 4: What are the types of travelers and which types of lanes can they use?

Query 1

Is is possible to cross at Y POE by X mode? - The ontology will be queried, what is the value of a particular mode at the particular POE. In case the number will be higher than 0, the answer will be YES. On the other hand, the POE is not equipped with the infrastructure for the particular crossing.

Example: Is it possible to cross at BOTA POE by commercial vehicle mode?

```
SELECT ?commercialVehicle
WHERE {
epj:BOTA epj:hascommercialVehicle ?commercialVehicle.
```

```
}
```

Query 2

Which lane can a Z traveler use? - The possible lanes may be identified by searching for the predicates epj:canUse that link the subclass Z of epj:Traveler with epj:Lane. The query will return a list of possible lanes which the traveler Z can use.

Example: Which lane can a SENTRI traveler use?

```
SELECT ?lane ?traveler

WHERE {

?traveler rdf:type dbo:Person.

?traveler rdfs:label "SENTRITraveler".

?traveler epj:canUse ?lane.

}
```

Query 3

What type of traveler can cross in X mode? This query identifies the predicate epj:canCrossAs between the instance of the class dbo:Person with the instance X of the class epj:TransportMode.

Example: What type of traveler can cross in pedestrian mode?

```
SELECT ?traveler

WHERE {

?transportMode rdf:type epj:TransportMode.

?transportMode rdfs:label "CommercialVehicle".

?traveler rdf:type dbo:Person.
```

```
?traveler epj:canCrossAs ?transportMode.
}
```

Query 4

What are the types of travelers and which types of lanes can they use? For each type od traveler, the query identifies if there is property "epj:canUse" between each instance of class epj:LaneType. The result of the query will list all combinations of types of travelers with the lane types they can use.

```
SELECT ?
WHERE {
?traveler rdf:type dbo:Person.
?lanetype rdf:type epj:LaneType.
?traveler epj:canUse ?lanetype.
}
```

7. Conclusion

7.1 Summary of research

The thesis has identified and mapped the border crossing system between the City of El Paso, Texas, U.S. and Ciudad Juarez, Chihuahua, Mexico. It provides systematic descriptions of services at the POEs, the actors, users, activities and the interactions between them using the UML. Special focus was paid to the northbound commercial crossing.

Important part of the thesis is focused on describing the system with UML diagrams. There were created 6 use case diagrams mapping the structure of the border crossing. Moreover 2 activity diagrams describing the detailed process of border crossings were also created. The diagrams can be applied in multiple cases e.g. to understand the structure of the system or when modeling and simulating any part of the border crossing.

The thesis also proposes a design of ontology focused on the border crossing. The ontology covers the core of the system, it describes the hierarchy of ports of entry, types of lanes and modes of travel together with their limitations on the travelers.

7.2 Limitation

The main limitations of the research was the scarcity of publicly available information about the system. Moreover, some of the information are available only in Spanish. The main source of information in the early stage were structured interviews with frequent travelers

and a former (retired) CBP officer. In the second phase, the information were supplemented based on the visual observation during the border crossing. Finally, after the information were described using the various diagrams, they were presented to frequent travelers for comments and modified based on their feedback.

7.3 Future research

The thesis has collected, organized and presented the information via UML and ontology. The descriptions serves as the reference of the border crossing systems in the El Paso-Ciudad Juarez area.

The work that has been performed in thesis may be continued in multiple ways. Firstly, the thesis can be widened with other types of diagrams that widens the possible area of using the thesis e.g. class diagram, state machine diagram, or sequence diagram. Secondly, the existing diagrams can be added to describe southbound crossing as well as additional services of the northbound crossing.

Lastly, the biggest potential could be in using the ontology. The existing ontology covers only the core of the system, and it was meant to be extended based on the additional research needs. This will provide possibility to answer wide area of questions, based on the datasets that will extend the core design.

One potential application of the ontology is a base work for machine learning program that can be used for helping travelers with choosing the best way to cross while considering multiple factors. In my future research I would like to mostly focus on adding multiple data sets into the ontology and monitor the effects of certain events on border wait times.

Using the ontology together with machine learning brings possibility to us it as a tool for recommending travelers the best way to cross the border based on their preferences, holidays, or weather. Additionally, it could be also extended with the location of the traveler, so the ontology could also consider the travel times to the ports of entry.

References

1. *Land ports of Entry Overview*. 2018. Available also from: https://www.gsa.gov/real-estate/gsa-properties/land-ports-of-entry-overview.

2. *Texas-Mexico international bridges and crossings*. Texas Department of Transportation, 2015. Available also from: https://ftp.dot.state.tx.us/pub/txdot-info/iro/international-bridges.pdf.

3. *Secure Electronic Network for Travelers Rapid Inspection (SENTRI)*. Custom and Border Protection, [n.d.]. Available also from: https://www.cbp.gov/sites/default/files/documents/FAST\20Fact\20Sheet\20-\20FINAL\20\28web\20ready\29.pdf.

4. *FAST lanes*. U.S. Customs and Border Protection, [n.d.]. Available also from: https://www.cbp.gov/travel/trusted-traveler-programs/fast.

5. U.S. Customs and Border Protection, [n.d.]. Available also from: https://www.cbp.gov/border-security/ports-entry/cargo-security/ctpat.

6. *Ready lanes*. U.S. Customs and Border Protection, [n.d.]. Available also from: https://www.cbp.gov/travel/clearing-cbp/ready-lanes.

7. *Official Trusted Traveler Program website: Department of Homeland Security*. [N.d.]. Available also from: https://ttp.dhs.gov/.

8. *Quiénes Somos - Fideicomiso de Puentes fronterizos de Chihuahua*. [N.d.]. Available also from: https://puentesfronterizos.gob.mx/quienes-somos-fideicomiso-de-puentes-fronterizos-chihuahua.php.

9. *Mission, Department of Homeland Security*. [N.d.]. Available also from: https://www.dhs.gov/mission.

10. *U.S. Customs and Border Protection STRATEGY 2021–2026*. U.S. Customs and Border Protection, 2020.

11. *¿Qué hacemos?* [N.d.]. Available also from: https://www.gob.mx/inm/que-hacemos.

12. *The International Boundary and Water Commission - its mission, organization and procedures for solution of boundary and water problems*. [N.d.]. Available also from: https://web.archive.org/web/20150527231405/http://www.ibwc.state.gov/About_Us/About_Us.html.

13. *About Us*. [N.d.]. Available also from: https://www.tabc.texas.gov/about-us/.

14. NOY, Natalya F.; MCGUINESS, Deborah L. *Ontology Development 101: A Guide to Creating Your First Ontology*. Stanford University, [n.d.]. Available also from: https://protege.stanford.edu/publications/ontology_development/ontology101-noy-mcguinness.html.

15. *OMG Unified Modeling Language (OMG UML), Version 2.5.1*. Object Management Group, 2017. Available also from: https://www.omg.org/spec/UML/2.5.1/PDF.

16. *Sparx Systems*. [N.d.]. Available also from: https://sparxsystems.com/.

17. *OWL Web Ontology Language Overview*. W3C, 2004. Available also from: https://www.w3.org/TR/owl-features/.

18. W3Schools, [n.d.]. Available also from: https://www.w3schools.com/xml/xml_namespaces.asp.

19. *Arrival/departure forms: I-94 and I-94W*. [N.d.]. Available also from: https://www.cbp.gov/travel/international-visitors/i-94.

20. *Customs Duty Information*. [N.d.]. Available also from: https://www.cbp.gov/travel/international-visitors/kbyg/customs-duty-info.

21. *Port of Entry*. [N.d.]. Available also from: https://dbpedia.org/page/Port_of_entry.

List of Figures

Glossary

UML	Unified Modeling Language
BWT	Border Wait Time
POE	Port of entry
POEs	Ports of entry
CBP	U.S. Customs and Border Protection
DHS	U.S. Department of Homeland Security
IBWC	International Boundary and Water Commission
RDF	Resource Descriptive Framework
OWL	Web Ontology Language
XMP	Extensible Markup Language
RFID	Radio-frequency identification