Ontology-Driven Integration of Data for Freight Performance Measures

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ONTOMETRY-DRIVEN INTEGRATION OF DATA FOR FREIGHT PERFORMANCE MEASURES

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Eduardo Javier Torres

2016
ONTOGRAPHY-DRIVEN INTEGRATION OF DATA FOR FREIGHT PERFORMANCE MEASURES

by

EDUARDO JAVIER TORRES, BSCE

THESIS

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Abstract

Transportation performance measures are defined as quantitative and qualitative indicators that rely on data or information to explain mobility, congestion, safety, environmental and other factors. Though performance measures have been used for freeways and other highways, not many have been specified and applied to the freight transportation system. Recently, freight performance measures have been recommended by Federal Highway Administration to quantify the operating efficiency of the freight transportation system on existing infrastructures. This research seeks to expand this concept and to develop a comprehensive freight performance measurement framework. The expanded framework recommended in this thesis consists of four criteria: safety, mobility, congestion, and environment. Each criterion consists of several qualitative and quantitative indicators. An ontology approach is used to integrate data that come from different sources, formats, updating frequencies and etc. A concept map is developed to better explain the relationships between the freight data and design the ontology. Relevant data was identified to answer questions about the freight performance. The proposed freight performance measurement framework and the ontology-based data integration proposed in this manuscript may contribute to decision-making of traffic engineers, transportation planners, truck companies, and future researchers. This work is important in the context of Smart Cities where metrics are important to evaluate city performance.
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1 Introduction

1.1 Importance of Freight Transportation

Freight is the transportation of goods whether by water, land, or air. Freight transportation is essential to the economy as it is the mode of transporting goods around the nation and in and out of the country. Freight transportation also affects the everyday life of the people as it affects traffic, safety in the road, and the environment.

In 2013, the transportation industry in the United States moved a total of 20,063 million tons of freight, or a daily average of 55 million tons of freight valued at about $49.3 billion/day. Truck is the mode of transportation that moves the most freight tons at about 70% of the freight (BTS, 2015).

There are about 10.5 million trucks in the United States’ highways which are about 4.1% of all the registered vehicles. The National Highway System is about 227,000 miles long and within the system there are 14,530 miles of highways that carry more than 8,500 trucks per day (on sections where at least one of four vehicles is a truck). The Bureau of Transportation Statistics (BTS) predicted that by 2040 the miles that carry 8,500 trucks per day will increase more than 175 percent from 2011, to 42,000 miles. As mentioned before, the presence of trucks on highways causes congestion. In 2011, 13,500 miles of the National Highway System slowed down during its peak hours and 8,700 miles had stop-and-go conditions. In 2040, BTS predicted that peak hour congestion will cause traffic to slow down on 28,000 miles and cause stop-and-go conditions on an additional 46,000 miles.

In 2014, 11.2 million truck-trips crossed the U.S. border from Mexico with a total of 3.8 million loaded containers and another 5.8 million truck-trips crossed the border from Canada.
with a total of 4.1 million loaded containers. The number of incoming trucks in the United States-Canada border as well as in the United States-Mexico border has changed. At the Canadian border, there has been a decrease of 17.7 percent in trucks coming into the United States while at the Mexican border the incoming truck traffic has increased by 19.6 percent between 2000 and 2014 (BTS, 2015).

Freight transportation and warehousing employ 4.6 million employees. Trucking is the sector with the most employees, with about 1.4 million. Trucking is also the sector with the biggest growth of employees since 1990 with a 26 percent increase. In 2014 there were approximately 2.83 million truck drivers (BTS, 2015).

Safety and energy consumption are two major concerns in the freight transportation industry. In 2013, there were a total of 3,964 fatalities in crashes involving trucks which is approximately 12 percent of all highway fatalities (BTS, 2015). Freight transportation contributes to most hazardous material incidents. In 2014 there were a total of 15,284 hazardous materials incidents in U.S. highways. These incidents mostly occur because of human error or packaging failure. Even though there has been a growth in freight demand, there has been a decline in fuel consumption. From 2007 to 2013 there was an 8.3 percent decline in truck fuel consumption (BTS, 2015). Trucks are the biggest contributors of freight emissions in the United States. Truck emissions have decreased since the beginning of the century due to the improvement in vehicle engineering and stricter environmental regulations. On the other hand, increase in truck freight movement (in terms of vehicle-miles traveled) has caused increases in emissions. There has been a 63.1 percent reduction in NOx emissions by trucks but there has been a 76.4 percent increase in greenhouse emissions (CO2, CH4, N2O, and HFC) from trucks (BTS, 2015).
The demand in freight transportation has grown and has been affecting the transportation from the local to national highways. The necessity of measuring transportation outcomes of the different modes has grown as well. Therefore, it is necessary to provide performance measurements in the freight transportation network. Performance measures for freight transportation help to measure efficiency, effectiveness, capacity, safety, security, infrastructure condition, energy, impacts on the environment and etc. Freight performance measures are important for evaluating the condition of the freight system, identifying problems, and setting priorities on actions to resolve those problems. Performance measurements also benefit the economy because it supports decisions about investments, operations, and policies for both the public and private sectors. The freight performance measurements present information that can help traffic engineers, urban and transportation planners, warehouse owners, truck drivers, and all stakeholders in the freight supply chain. It is also important to the public as freight transportation creates congestion, safety, noise and air quality issues along the freight corridor that affect their quality of life of the surrounding residents.

According to National Cooperative Freight Research Program, “freight performance measurement is challenged both by an abundance of data and by a lack of complete data for many important freight system performance functions. Sorting and selecting from the voluminous available data sources is one daunting challenge. Closing data gaps is another” (NCFRP, 2011). In this research, a proposed framework of identifying and integrating freight data will be proposed to meet the challenges.
1.2 Objective

The first objective of this research is to improve current freight performance measurements by integrating heterogeneous and distributed freight data that could be of interest to stakeholders (such as support traffic engineers, transportation planners, warehouse owners, truck companies) to better understand the relationships between different freight data.

The second objective is to demonstrate how the data may be integrated using an ontology-based approach to support traffic engineers, transportation planners, warehouse owners, truck companies, and future researchers in making freight transportation related decisions.

1.3 Outline

The thesis starts with Chapter 1 which gives the importance of the freight transportation in the United States. Chapter 2 consists of the literature review on freight performance measures and semantic web. The third chapter explains the different sources and formats of freight data. The freight performance measurement framework being proposed is presented in Chapter 4. The ontology design using a concept map to understand the relationships between the data is described in Chapter 5. Chapter 6 describes the implementation of the ontology. Finally, Chapter 7 discusses the collaborative effort between the civil engineering and computer science domain in this research, the challenges and future works. Chapter 8 presents the conclusions and contributions of this research.
2 Literature Review

2.1 Freight Performance Measures

The National Cooperative Freight Research program (NCFRP) published a report in 2011 aiming to develop measures to assess the performance the freight transportation system. They define freight performance measures as quantitative and qualitative indicators that rely on data or information to explain the influence of freight on safety, the environment, and other transportation factors. The areas emphasized include efficiency, effectiveness, capacity, safety, security, infrastructure condition, congestion, energy, and the environment. The report talked about freight movement in highway, railroad, air, and in water but only the freight performance on highways was focused on. The report is divided into how the private and public sector use the performance measures and how measures should be presented to each of those sectors. The private sector has four types of performance measures (NCFRP 2011) which are the following

- Foundational or basic financial measures
- Productivity or internal performance measures
- Competency or innovation measures comparing to external performance,
- Resource allocation or investment-tradeoff allocation measures.

The NCFRP recommended use both quantitative and qualitative measures be used by the public sectors. However, it cautioned users to watch out for the tendency to select the easily accomplished measures while avoiding the difficult, anticipate powerful resistance of accountability. This means that engineers who developed the freight performance measurement framework must involve stakeholders in developing the measures, subject the measures to periodic review and evaluation, do not use too many of too few measures (NCFRP 2011).
According to NCFRP (2011), a big challenge in freight performance measurement is both the lack of complete data for many important indicators and on the other extreme the great quantity of data. Another big challenge is to sort and select from the plenty of data whatever that is meaningful. Most state Departments of Transportation (DOTs) use measures that are easy to obtain such as travel time, truck involved crashes, and pavement conditions. This becomes a debatable topic because it is not well defined if DOTs are really reporting measures that reflect the state of freight transportation or just use the measures because the data are readily available.

The Federal Highway Administration (FHWA) used the following criteria to select which measures should be included:

- Descriptive value – Is the measure clear and understandable?
- Technical appropriateness - how useful is the measurement in describing the effectiveness of the freight movement?
- Data availability - how difficult is it to obtain the data?
- Data cost - how much is to obtain the correct data?

States like Washington, Missouri and Minnesota which have the most experience in performance measurements (not necessarily for freight) only use between five to 10 measures. The most popular performance measures that are used throughout the states are seen in Table 2.1.
### Table 2.1: Examined Performance Measures (NCFRP)

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Typical Definition</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of Service (LOS)</td>
<td>Qualitative assessment of highway point, segment, or system using A (best) to F (worst) based on measures of effectiveness</td>
<td>11</td>
</tr>
<tr>
<td>Traffic Volume</td>
<td>Annual average daily traffic, peak-hour traffic, or peak-period traffic</td>
<td>11</td>
</tr>
<tr>
<td>Vehicle-Miles Traveled</td>
<td>Volume times length</td>
<td>10</td>
</tr>
<tr>
<td>Travel Time</td>
<td>Distance divided by speed</td>
<td>8</td>
</tr>
<tr>
<td>Speed</td>
<td>Distance divided by travel time</td>
<td>7</td>
</tr>
<tr>
<td>Incidents</td>
<td>Traffic interruption caused by crash or other unscheduled event</td>
<td>6</td>
</tr>
<tr>
<td>Duration of Congestion</td>
<td>Period of congestion</td>
<td>5</td>
</tr>
<tr>
<td>Percent of System Congested</td>
<td>Percent of miles congested (usually defined based on LOS E or F)</td>
<td>5</td>
</tr>
<tr>
<td>Vehicle Occupancy</td>
<td>Persons per vehicle</td>
<td>5</td>
</tr>
<tr>
<td>Percent of Travel Congested</td>
<td>Percent of vehicle-miles or person-miles traveled</td>
<td>4</td>
</tr>
<tr>
<td>Delay Caused by Incidents</td>
<td>Increase in travel time caused by an incident</td>
<td>3</td>
</tr>
<tr>
<td>Density</td>
<td>Vehicles per lane, per period</td>
<td>3</td>
</tr>
<tr>
<td>Rail Crossing Incidents</td>
<td>Traffic crashes that occur at highway-rail grade crossings</td>
<td>3</td>
</tr>
<tr>
<td>Recurring Delay</td>
<td>Travel time increases from congestion; this measure does not consider incidents</td>
<td>3</td>
</tr>
<tr>
<td>Travel Costs</td>
<td>Value of driver’s time during a trip and any expenses incurred during the trip (vehicle ownership and operating expenses or tolls or traffic)</td>
<td>3</td>
</tr>
<tr>
<td>Weather-related Incidents</td>
<td>Traffic interruption caused by inclement weather</td>
<td>3</td>
</tr>
<tr>
<td>Response Time to Incidents</td>
<td>Period required for an incident to be identified, to be verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene</td>
<td>2</td>
</tr>
<tr>
<td>Commercial Vehicle Safety Violations</td>
<td>Number of violations issued by law enforcement based on vehicle weight, size, or safety</td>
<td>1</td>
</tr>
<tr>
<td>Evacuation Clearance Time</td>
<td>Reaction and travel time for evacuees to leave an area at risk</td>
<td>1</td>
</tr>
<tr>
<td>Response Time to Weather-related Incidents</td>
<td>Period required for an incident to be identified, to be verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene</td>
<td>1</td>
</tr>
<tr>
<td>Security for Highway and Transit</td>
<td>Number of violations issued by law enforcement for acts of violence against travelers</td>
<td>1</td>
</tr>
<tr>
<td>Toll Revenue</td>
<td>Dollars generated from tolls</td>
<td>1</td>
</tr>
<tr>
<td>Travel Time Reliability</td>
<td>Several definitions are used</td>
<td>1</td>
</tr>
</tbody>
</table>
According to McMullen and Monsere (2010) there are five steps in the implementation of a freight performance measurement system.

1. First, is to identify the measures which are meaningful and measurable.
2. Second, collect data for the measures chosen.
3. Then, select models in measures that estimation is required.
4. Next, calculate measures.
5. Finally, collect data and perform required estimation and calculations on a regular basis. It is important to have the measures be measured on regular basis to be able to see the improvements if any have been made and to have a more accurate data.

There are many different performance measures that are being used around the United States and for different reporting purposes. For example the Texas A&M Transportation Institute (TTI) uses 30 different measures every year when its updates their Annual Urban Mobility Scorecard (Schrank et al. 2015). The measures are divided into two categories, inventory measures and system measures. Inventory measures are the following: population, peak travelers, commuters, daily vehicle-miles travel (freeway), lane-miles (freeway), daily vehicle-miles travel (arterial streets), lane-miles (arterial streets), annual passenger-miles of travel, annual unlinked passenger trips, value of time, commercial cost, gasoline cost, and diesel cost (Schrank 2015). The system measures are the following: congested travel, congested system, congested time, total fuel, fuel per peak auto commuter, total delay, delay per peak auto commuter, travel time index, commuter stress index, freeway planning time index (95th percentile), freeway planning time index (80th percentile), congested CO\(_2\), CO\(_2\) per peak auto commuter, truck congestion cost, truck commodity value, Congestion total cost, and congestion cost per peak auto commuter.
McMullen and Monsere (2010) wrote a report about the freight performance measures in the State of Oregon. The report divided the performance measures into seven categories which they thought were the most significant for the freight system. The categories are the following: safety, maintenance/preservation, mobility, congestion, accessibility, environmental, and connectivity.

Safety is the most frequently listed policy goal by states that have freight performance measurement systems (McMullen and Monsere 2010). Safety involves the fatality, injury, and crash rates the involve freight related vehicles. Safety is important in the freight system because it causes delay as well as a loss of money. According to McMullen & Monsere (2010) the recommended performance measures for safety are motor carrier crash rate and triple trailer crash rate, motor carrier truck at-fault crash rate, and total cost of freight loss and damage from accidents per VMT.

Mobility is an essential part of the freight system because it describes how the system is moving in a timely fashion. Mobility measures are different in many states because each state uses different indicators to calculate this measure.

Congestion is very important in the freight system but can be overlapped by mobility because mobility and congestion can have the same measures for example the travel time index. The congestion category involves both the freight and passenger transportation because both tare affected by congestion by the same way. The recommended mobility and congestion measurers according to McMullen & Monsere (2010) are the following: hours of congested conditions per day, average hours of delay per day for freight vehicle, travel time index, buffer index on fright-significant links, and average travel time.
Environment is another important category because transportation affects the environment and the quality of life. Examples of environmental measures are volatile organic compounds, nitrous oxides, carbon monoxide, ozone, particulates and greenhouse gases.

2.2 Semantic Web

According to the Scientific American article The Semantic Web (Berners-Lee et al. 2001), “The semantic web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation.” Semantic web has two main functions: (1) it provides common formats for integration and combination of data drawn from diverse sources; (2) it provides the language for recording how the data relates to real world objects (W3C 2015).

The goal of using Semantic Web is to create a common framework that allows data to be shared and reused across applications, enterprises, and community boundaries, to be processed automatically by tools as well as manually, including the revelation of possible new relationships among pieces of data. Semantic Web may be used in different application areas, including data integration, resource discovery and classification, cataloging, intelligent software agents, content rating, describing intellectual property rights of web pages (W3C 2015).

2.2.1 Ontology

The term ontology has been long been used as a philosophical sense but it has only recently emerged in a computational sense in the engineering community. In philosophical terms, ontology is the study of the kinds of things that exist and ontologies “carve the world at its joints” (Chandrasekaren et al. 1999). From the engineering perspective it may mean two things. Frist, ontology is a representation vocabulary specialized to a subject matter or relationship
between elements. More specifically, ontology is the conceptualization of the vocabulary. The second definition is used less often but is describing a domain (Chandrasekaren et al. 1999). In Semantic Webs, ontology is a vocabulary used to define the terms and relationships between them that is used to annotate data as the building block in Semantic Web (W3C 2015).

Ontology-based data integration can help to understand relationships between datasets and could lead to finding new implicit relationships between such datasets. For example, traffic information applications may help freight drivers in deciding at what time and what routes they should take, while traffic engineers may use the same traffic information to analyze traffic and then making traffic management decisions. After understanding the needs of both the truck drivers and traffic engineers, a new application may be developed as a decision support tool to help traffic engineers consider freight transportation in the decision making process and to facilitate the driver’s job function.

An ontology is at the backbone of the proposed framework for the integration of freight data. An ontology is used to annotate heterogeneous dataset and to define the relationships between them. This being said, it is essential to perform an effective semantic analysis of the data being represented because otherwise it could lead into an unclear knowledge base. Selecting the right vocabulary that describes the concepts and relationships between data sets is important as well.
2.2.2 Concept Map

A concept map is a type of graphical presentation that helps to organize and represent knowledge of a subject. Concept maps were developed in 1972 by Joseph Novak. It was intended to teach elementary students science concepts. Since then it has been adopted by many teachers at all levels (Markham et al. 1994). It is used in many applications such as to organize ideas, show relationships, generate questions about your topic, and more.

Concept maps are very simple to build. First, a main idea, topic or issue is brought to be focused on. With the main idea already known, it is good to come up with a question that will help to determine the context of the concept map. The next step is to determine the key concepts that relate to the topic. The concepts should be ranked, in order, from general concepts to specific concepts. That is, more general, inclusive concepts should come first, and then link to smaller, more specific concepts. Finally, these concepts are connected by creating linking phrases and words. It is important to add cross-links, which connect concepts in different areas of the map, to further illustrate the relationships (Inspiration 2016). An example of a concept map is given in Figure 2.1. Concept maps are very easy to follow and are the best way to represent a concept.
2.2.3 Visual Understanding Environment

Visual Understanding Environment (VUE) is a software tool for concept mapping. It is developed from an open source project at Tufts University, Massachusetts (Tufts 2015). It was developed to support teaching, learning and research and for anyone who needs to organize, contextualize, and access digital information. VUE provides two interfaces; a concept mapping interface and an interface to organize digital content in non-linear ways. VUE has its unique features that separate it from similar applications. It has the ability to help users to integrate, organize and contextualize electronic content. VUE also has a pathways feature that allows users to create annotated trails through their maps. Another unique feature that VUE has is that it provides in-depth analysis of maps, with the ability to merge maps and export connectivity matrices to import in statistical packages. VUE has the ability to apply semantic meaning to the maps, by way of ontology and metadata schemas (Tufts 2016). VUE has been applied for different sources and ideas such as for research, administration, learning tool, and more.
2.2.4 Summary

In this Chapter the concept of ontologies, which are at the core of our freight-data integration framework, has been discussed. In this thesis, VUE will be used to develop a concept map describing the different freight data integrated in the proposed framework. The concept map will help in developing the ontology to be able to answer competency questions.
3 Freight Data

Freight data comes from different sources and different formats such as Microsoft Excel worksheets, Adobe Portable Document Format (PDF) files, or in a website. In this chapter, freight data from different sources such as Texas Department of Transportation, Texas A&M Transportation Institute, U.S. Environmental Protection Agency, and Camino Real Regional Mobility Authority are described.

3.1 Texas Department of Transportation

The Texas Department of Transportation (TxDOT) is a main source of freight and non-freight transportation data. TxDOT provides essential data from all parts of Texas and it is easy to retrieve data for a specific city in the state.

3.1.1 Crash Report Information System

TxDOT provides a database of all the reported crashes that occurred within the State of Texas, called Crash Records Information System (CRIS). The data is given in a Microsoft Excel file where crash records for each year are given in a separate worksheet. Each Excel worksheet has detailed information about each crash. The crash attributes given are: crash fatality, commercial motor vehicle involved, school bus involved, active school zone involvement, crash date, crash time, crash id, city, county, latitude, longitude, street, speed, weather condition, light condition, surface condition, notify time, arrival time, collision type, object struck, other factor, injuries, and more. Figure 3.1 shows an example of how the data is presented in a worksheet.
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
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<td>Case_ID</td>
<td>TxDOT_Cond_ID</td>
<td>Investigator_Hour_Time</td>
<td>Investigator_Arr_Time</td>
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<td>Crash_ID</td>
<td>City_ID</td>
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Figure 3.1: TxDOT CRIS Worksheet
3.1.2 Annual Average Daily Counts

TxDOT collects traffic volumes in all of its 25 districts. Every year, TxDOT makes the traffic count data available through its website (http://www.txdot.gov/inside-txdot/division/transportation-planning/maps.html) in PDF format. TxDOT provides a PDF file for each district and each file is further divided into several traffic maps showing the volumes at different locations. An example of a traffic map may be seen in Figure 3.2.

Figure 3.2: Volume Counts from Texas Department of Transportation
3.2 Texas A&M Transportation Institute

Texas A&M Transportation Institute (TTI) is a major source for any data related to transportation. TTI is an organization that conducts transportation research in many areas such as engineering, planning, economics, policy, landscape architecture, environmental sciences, computer science, and social sciences. With hundreds of researchers, TTI has developed many databases, datasets, websites and annual reports. Examples of TTI’s products that are of interest to freight performance measurement system are the Annual Urban Mobility Scorecard and the Border Crossing Information System (BCIS).

3.2.1 Annual Urban Mobility Scorecard

Every year, TTI develops a mobility scorecard for many cities in the United States (Schrank et al. 2015) Some of their estimates come from INRIX, a private company that provides travel time information to a variety of customers (Schrank et al. 2015). TTI provides an Excel worksheet with all the mobility measures for major cities in the United States. The different mobility measures that are included in the worksheet are: population, daily vehicle miles of travel, cost components (value of time, commercial cost, gasoline and diesel price), percent of travel congested, percent of system congested, congested time, annual excess fuel consumed, annual delay, travel time index, commuter stress index, and congestion cost. This dataset has many congestion indicators; average peak hour delay, congestion cost, congestion time, percent of system congested, percent travel congested, gasoline price, diesel price, travel time index, commuter stress index, and value of time. Figure 3.3 shows part of the scorecard worksheet.
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Figure 3.3: TTI Urban Mobility Scorecard Worksheet
3.2.1 Border Crossing Information System

The Border Crossing Information System (BCIS) is a website (http://bcis.tamu.edu/Commercial/en-US/index.aspx) that gives real-time information about crossing times (northbound) for both passenger vehicles and commercial vehicles at the United States-Mexico border. The website is developed and maintained by TTI but it is funded by the TxDOT and the Federal Highway Administration. The website has archived data that may be retrieved and used in the average waiting time calculation. BCIS give crossing time information at eight different commercial vehicle ports of entry at the United States-Mexico border (7 from Texas and 1 from Arizona). Figure 3.4 shows how the archived data looks like at the website. The displayed data is the monthly average crossing time of all the commercial vehicles on weekdays at a particular port of entry.
Figure 3.4: Average Crossing Time (Northbound) per Month for Commercial Vehicles in 2014 at Ysleta Port of Entry

3.3 U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) is a federal agency that ensures the environmental protection through research, monitoring, standard setting, and enforcement activities. EPA provides tools to calculate environmental greenhouse gases in its website (https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator).
3.3.1 **Greenhouse Gas Equivalencies Calculator**

The calculator provided by the EPA website estimates the CO₂ emissions by the number of gallons of gasoline consumed. The conversion factor that EPA uses to calculate CO₂ emissions is:

\[ 8,887 \text{ grams of CO}_2 / \text{gallon of gasoline} = 8.887 \times 10^{-3} \text{ metric tons CO}_2 / \text{gallon of gasoline} \]

3.4 **Camino Real Regional Mobility Authority**

In the State of Texas there are eight Regional Mobility Authorities (RMAs), which belong to a political subdivision of the State of Texas. The RMAs have the authority to study, evaluate, design, finance, acquire, construct, maintain, repair and operate transportation projects in their respective geographical area (http://www.crrma.org/history.asp). The Camino Real Regional Mobility Authority (CRRMA) is the RMA in charge of the El Paso region.

3.4.1 **Financial Report**

Every fiscal year Camino Real Regional Authority produces a financial report presenting its financial statements of its activities. CRRMA provides its annual reports, in PDF files at their website (http://www.crrma.org/documents.asp) for public viewing and download. Part of the report shows its operating revenues. The Cesar Chavez Border Highway is the only toll road in El Paso which is managed by CRRMA. The CRRMA annual report has toll revenue and other operational statistics.

3.5 **Summary**

Freight Data is heterogeneous and distributed among several agencies and sources and is represented in different formats. This chapter describes the types of data related to freight
transportation that is available from TxDOT, TTI and CRRMA. They come in the forms of Microsoft Excel worksheets, PDF files and at websites. The data also comes in different time and spatial scales.
4 Freight Performance Measurement Framework

4.1 Performance Metric

Freight performance measures are quantitative and qualitative indicators that rely on data to explain freight mobility, congestion, safety, environmental and other factors. To be able to explain these factors, in this research, the performance measures are divided into four different criteria that measure the performance of different aspects of the freight transportation system.

4.2 Criteria

The four criteria are safety, mobility, congestion, and environmental sustainability. Each criterion is chosen for its ability to explain different important aspects of freight transportation.

- Safety is always regarded as the most important factor in highway transportation as freight shares the highways that are being used by the public.
- Mobility is measured because freight transportation is a very important contributor to the economy. Freight moves constantly its movement needs to be very efficient.
- Congestion is another criterion that affects the traveling and non-traveling public and therefore it needs to be included as a criterion. In addition, congestion may increase the cost of freight transportation as they lose time in traffic.
- Environmental sustainability is a topic that recently has been given a lot of attention to as it is related to air quality and public health. Having an environmental criterion helps to quantify how freight affects the environment.
4.3 Indicators

Each criterion described in Section 4.2 consists of several quantitative and qualitative indicators. The indicators are selected through the literature review in Chapter 2. When selecting these indicators it was important to answer the questions (NCFRP 2011):

- Descriptive value - is the indicator clear and understandable?
- Technical appropriateness - how useful is the indicator in describing the freight movement?
- Data availability- how difficult is it to obtain the data?
- Data Cost - how expensive is it to obtain the data?

The data found for the indicators is critical as it is important for it to be accurate and from a trustful source.

Table 4.1 shows the list of the indicators, grouped under each of the four criteria. The table is divided into the four criteria, safety, mobility, congestion, and environmental sustainability. The meaning of each indicator is shown as well as its measurement frequency. The data source of each indicator is also shown. Some indicators have blank in the Data Source column as its data is not yet found (for the El Paso region). However, based on the literature review, they are important and should be included.

In Table 4.1 there is also a column that lists potential users who may think that the indicators are critical in their decisions. It is important to understand that different users may have different needs and may not need all the indicators listed in Table 4.1. From experience and through the literature review the column was filled but the indicators needs to be validated by the end users.
<table>
<thead>
<tr>
<th>Criterion</th>
<th>Indicator</th>
<th>Meaning</th>
<th>Measurement Unit</th>
<th>Data Source</th>
<th>Potential Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>Incidents</td>
<td>Traffic interruption caused by crash or other unscheduled event</td>
<td>Average of incidents per year</td>
<td>TX DOT CRIS Data</td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td></td>
<td>Weather-related Incidents</td>
<td>Traffic interruption caused by inclement weather</td>
<td># defined incidents/year</td>
<td>TX DOT CRIS Data</td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td></td>
<td>Response Times to Incidents</td>
<td>Period required for an incident to be identified, to be verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene</td>
<td>minutes</td>
<td>TX DOT CRIS Data</td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td></td>
<td>Evacuation Clearance Time</td>
<td>Reaction and travel time for evacuees to leave an area at risk</td>
<td>hours</td>
<td></td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td></td>
<td>Commercial Vehicle Safety Violations</td>
<td>Number of violations issued by law enforcement based on vehicle weight, size, or safety</td>
<td># of violations/truck/year</td>
<td></td>
<td>Truck Companies</td>
</tr>
<tr>
<td></td>
<td>Delay caused By Incidents</td>
<td>Increase in travel time caused by an incident</td>
<td>hours/incident</td>
<td></td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td></td>
<td>Fatal incidents</td>
<td>Fatalities involved in an incident</td>
<td># of fatal incident per year</td>
<td>TX DOT CRIS Data</td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td></td>
<td>Security for Highway and Transit</td>
<td>Number of violations issued by law enforcement for acts of violence against travelers</td>
<td>cases per year</td>
<td></td>
<td>Truck Companies</td>
</tr>
<tr>
<td>Congestion</td>
<td>Average Peak Hour Delay</td>
<td>Delay caused by congestion during the peak hours</td>
<td>hour/veh</td>
<td></td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td></td>
<td>Recurring Delay</td>
<td>Travel time increases from congestion; this measure does not consider incidents</td>
<td>veh-hour</td>
<td></td>
<td>Truck Companies</td>
</tr>
<tr>
<td></td>
<td>Congestion Cost</td>
<td>The yearly value of delay time and wasted fuel</td>
<td>$/year</td>
<td>TTI Urban Mobility Report</td>
<td>Truck Companies</td>
</tr>
<tr>
<td></td>
<td>Congestion Time</td>
<td>Period of congestion</td>
<td>hour/day</td>
<td>TTI Urban Mobility Report</td>
<td>Truck Companies</td>
</tr>
<tr>
<td></td>
<td>Percent of system Congested</td>
<td>Percent of miles congested (LOS E or F)</td>
<td>%</td>
<td>TTI Urban Mobility Report</td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td></td>
<td>Percent of Travel Congested</td>
<td>Percent of vehicle-miles or person-miles traveled in congestion</td>
<td>%</td>
<td>TTI Urban Mobility Report</td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td>Environmental</td>
<td>Environmental Sustainability</td>
<td>Amount of NOx, CO, SO2 emission per year</td>
<td>tons/year</td>
<td></td>
<td>MPO</td>
</tr>
<tr>
<td></td>
<td>Gasoline price</td>
<td>Cost of gasoline per gallon</td>
<td>($/gallon)</td>
<td>TTI Urban Mobility Report</td>
<td>Truck Companies</td>
</tr>
<tr>
<td></td>
<td>Diesel price</td>
<td>Cost of diesel gasoline per gallon</td>
<td>($/gallon)</td>
<td>TTI Urban Mobility Report</td>
<td>Truck Companies</td>
</tr>
<tr>
<td></td>
<td>CO2 emission</td>
<td>CO2 emissions due to congestion</td>
<td>tons/year</td>
<td><a href="http://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator">http://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator</a></td>
<td>MPO</td>
</tr>
<tr>
<td>Criterion</td>
<td>Indicator</td>
<td>Meaning</td>
<td>Measurement Unit</td>
<td>Data Source</td>
<td>Potential User</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------</td>
<td>---------</td>
<td>------------------</td>
<td>-------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Mobility</td>
<td>Level of service (LOS)</td>
<td>Qualitative assessment of highway point, segment, or system using A (best) to F (worst) based on measures of effectiveness</td>
<td>LOS from A to E</td>
<td><a href="http://ftp.dot.state.tx.us/pub/bdot-info/tpp/traffic_counts/2014/elp-base.pdf">http://ftp.dot.state.tx.us/pub/bdot-info/tpp/traffic_counts/2014/elp-base.pdf</a></td>
<td>Traffic engineers, MPO, Truck Companies</td>
</tr>
<tr>
<td>Mobility</td>
<td>Traffic Volume</td>
<td>Annual average daily traffic, peak-hour traffic, or peak-period traffic</td>
<td>veh/day</td>
<td>Traffic engineers, MPO</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Travel Time</td>
<td>Distance divided by speed</td>
<td>minutes</td>
<td>Traffic engineers, MPO</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Speed</td>
<td>Average space mean speed</td>
<td>mph (average of all lanes)</td>
<td>Traffic Engineers, MPO</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Vehicle Occupancy</td>
<td>Persons per vehicle</td>
<td>passengers per vehicle</td>
<td>MPO</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Travel Time Reliability</td>
<td>Several definitions are used. Usually refers to day-to-day variation of travel time in the same time of day.</td>
<td>90th or 95th percentile travel times, buffer index, planning time index</td>
<td>Traffic Engineers, Truck Companies</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Vehicle-Miles Traveled</td>
<td>Volume times length</td>
<td>veh-mile</td>
<td>Traffic Engineers</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Value of Time</td>
<td>Cost of the time traveled</td>
<td>$/hour</td>
<td>TTI Urban Mobility Report, MPO, Truck Companies</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Density</td>
<td>Vehciles per distance per lane</td>
<td>veh/mile/lane</td>
<td>Traffic Engineers, MPO</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Travel Time Index</td>
<td>Ratio of travel time in congested conditions to the travel time in free-flow conditions</td>
<td>Dimensionless</td>
<td>TTI Urban Mobility Report</td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td>Mobility</td>
<td>Commuter Stress Index</td>
<td>Ratio of travel time for the peak direction to travel time at free-flow conditions</td>
<td>Dimensionless</td>
<td>TTI Urban Mobility Report</td>
<td>Traffic Engineers</td>
</tr>
<tr>
<td>Mobility</td>
<td>Travel Costs</td>
<td>Value of driver’s time during a trip and any expenses incurred during the trip (vehicle ownership and operating expenses or tolls or traffic)</td>
<td>$/trip</td>
<td>Truck Companies</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Port of Entry Average Waiting Time</td>
<td>Waiting times in border</td>
<td>minutes</td>
<td>Truck Companies</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Toll Revenue</td>
<td>Dollars generated from tolls</td>
<td>$/time period</td>
<td>MPO</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Truck Commodity Value</td>
<td>Value of goods moved by truck</td>
<td>Total $ per year</td>
<td>Truck Companies</td>
<td></td>
</tr>
</tbody>
</table>
5 Ontology Design for Freight Performance Measurements

Ontologies describe concepts and their relationships. This chapter presents the process followed to create the ontology at the core of the freight performance measurement framework. It extends the Ontology 101 (Noy and McGuinness 2001) by incorporating the creation of a concept map used to communicate across the domain experts and computer scientists who assisted in the creation and population of the ontology and developing an interface to query the resulting knowledge base. As a first step, a concept map was created to identify (i) relevant data for freight performance measurements; (ii) data sources and (iii) the relationships between the data. The initial concept map is extensible and contains traces of provenance (information of where the data was obtained).

5.1 Concept Map

To illustrate the relationships between the data sources relevant to each metric indicator, a concept map was developed using VUE (Visual Understanding Environment) tool (Tufts 2015). Nodes were used to identify data sources for each criteria and indicator. Different colors were used to represent different attributes that will be explained further in this chapter. Links were used to identify the relationships between the criteria and indicators.

5.1.1 Nodes

The first node identified in the concept map is the topic which is performance metric. Then, the “performance metric” node is split into the four criteria: safety, traffic congestion, environmental sustainability, and mobility as seen in Figure 5.1. Each criterion is split into its several indictors mentioned in the previous chapter.
Figure 5.1: Concept map showing division of Performance Metrics into Criterion

The metric and criteria nodes are coded in purple color. Each indicator node is color coded to represent the format of the relevant data: red for PDF file, green for Excel worksheet, pink for website, and gray for others, no data or unknown. Figure 5.2 shows the colors that each node is represented. Having different colors helps in the creation of the ontology. A specific node called “No data” was used to identify indicators for which data is not available at the time of creating this framework.
In the concept map, each indicator was split into sub-nodes that explain the properties of the indicators. For example, each indicator is split into the geographical area it covers and into its units. Another example is the indicator node “incidents” which has information about the street the incident occurred. The units of measurements are colored in blue and the geographical covered area is colored in yellow. The following figures are the concept map divided into the four different criterions.
Figure 5.3: Safety Criterion Concept Map Portion
Figure 5.4: Traffic Congestion Criterion Concept Map Portion
Figure 5.5: Environment Criterion Concept Map Portion
Figure 5.6: Mobility Criterion Concept Map Portion
A unique feature of VUE for the concept map is that it allows users to add notes in each
dnode. Each indicator node, therefore, has a note describing what the indicator means, its data
source and how to retrieve the data from the source. For example, Figure 5.4, it is seen that the
traffic congestion criteria is divided into its indicators. The indicators are in green color
representing the data format which is Excel. Each indicator is then divided into its properties. For
example average peak hour delay is divided into its measurement and the geographical area.
Each node had its own notes in them showing the source and the possible users of the
framework. The sources noted in this concept map were with data from El Paso, Texas region for
the year of 2014. As well it was noted that the time scales (e.g. daily, monthly, yearly, etc.).

5.1.2 Links

The relationships between the nodes in the concept map were shown by the links
connecting two nodes. Each link has a phrase or word to show how the two end nodes relate to
each other. The most common phrases use in the concept map is: “is indicator of”, “is part of”,
“has measurement” and “covers area”. These phrases and words used are the ontology language.
For example, seen in traffic congestion portion, Figure 5.4, the nodes are connected with links. In
“average peak hour” it is linked to “hour/veh” with a phrase in the link saying “has
measurement” which defines the relationship between average peak hour and veh/hr. average
peak hour also links to geographical area with a link phrasing covers area.

5.2 Conclusion

The design of the ontology was jumpstarted with a concept map which enables one to
visualize the indicators, the relationships between them and identify data. Adding criteria and
indicators to the concept map is always an option as the performance metric may expand in the
future. As more data is available, there will be more nodes and links in the concept map. The concept map is a great way to visualize the main concepts and their relationships in the ontology as well as identifying sources of data and communicating between domain experts (civil engineers) and computer scientists developing the ontology and knowledge base that will be used to answer questions about freight performance measurements.
6 Ontology Implementation

This Chapter describes how the knowledge base of the proposed framework was created from the concept map developed by domain experts and populated using the relevant data identified in a previous phase.

6.1 Data Processing

Data collection was the longest and most time consuming process in the creation of the proposed framework. Once the data was identified, the next step was to retrieve and integrate them. This allowed all the data to be integrated and annotated in the knowledge base and allows users to ask questions that require answers from a combination of data items from the same knowledge base.

6.1.1 Crash Data

As identified in Tables 4.1 and 4.2, TxDOT’s CRIS (2014) is the source to find the number of crashes, the fatal crashes, weather related crashes, and the response time to crashes. First, the data was filtered to identify records of crashes that happened in the county and city. The data was also filtered to keep the crashes that involved Commercial Motor Vehicles (CMV). Finding the number (frequency) of crashes was straightforward as it was the total number of crashes in the dataset. To find fatal crashes another easy filtration had to be done and that was to filter out the crashes that had fatalities. Weather-related crashes was more complicated, because the data had to be filtered a couple of times and assumptions had to be made on whether the crash was caused by weather. First, the weather condition ID had to be filtered to 2, 3, 4, or 6 which represented rain, sleet/hail, snow, blowing sand/snow respectively. The other column that had to be filtered was other factor ID which was filtered to 1 which meant “lost control or
skidded (icy or slick road, etc.).” The average response time was calculated by taking the difference between the notify time and the arrival time. A new column was added in the Excel worksheet to calculate the response time.

6.1.2 Mobility Data

TTI’s Annual Urban Mobility Scorecard (Shrank et al. 2015), although has “mobility” in its name, has many congestion indicators: average peak hour delay, congestion cost, congestion time, percent of system congested, percent travel congested. The report also has gasoline price, diesel price, travel time index, commuter stress index, and value of time. TTI provided the Urban Mobility Scorecard in an Excel worksheet. The worksheet included all the cities and years TTI has the data. The worksheet was filtered into the city and year of interest; for example El Paso, Texas and the year 2014. Once filtered, it was easy to retrieve the necessary data.

6.1.3 Border Crossing Time

To be able to retrieve the average border crossing time from the BCIS (http://bcis.tamu.edu/Commercial/en-US/queryArchivedData.aspx), there were a few steps to follow:

1. In the Select Performance Measure box “Monthly Performance Indicators” is selected.

2. In the Select a Port of Entry box one of eight bridges may be chosen, for example “Ysleta Bridge, El Paso, TX.”

3. In the Date Range boxes a one-year range may be selected, for example “from 01/01/2014 to 12/31/2014.”

4. Once the input data have been entered, a graph appears on the screen with six lines estimating average crossing time, buffer index, median crossing time, 95th percentile
time, sample size, and volume for each month of the year. Only the average crossing time was needed so the rest of the lines were cleared. The average crossing time for the whole year may be estimated by using the average monthly crossing time weighted by the monthly traffic volume.

6.1.4 Greenhouse Gas

According to U.S. EPA, gallons of gasoline consumed are used to calculate the CO$_2$ emissions. The number of gallons of gasoline used was obtained from the Annual Urban Mobility Scorecard (Schrank et al. 2015).

6.2 Ontology Implementation

After, defining the concepts of the framework ontology using a concept map, the next step was to use it to implement the freight performance measurement knowledge base. A customized program was created by students of the Cyberinfrastructure Applications course (Caballero et al. 2016). This customized program was written using Java with an extension of the OWLAPI (http://owlapi.sourceforge.net/). The Library OWLAPI provides a programming interface to create the classes, relationships and instances of the ontology. The nodes in the concept map were mapped to OWL classes and linked to either object properties or data properties and the data are the instances of the ontology. Classes are the entities in the domain, object or data properties are the relationships among these entities, and instances are the concrete examples of concepts within the domain (Rivera 2015). Once the ontology was implemented, the data was annotated using concepts and properties of the ontology and added to the ontology as individuals. The ontology was populated using the customized programs developed by computer science students, which deals with creating mash-ups of the data so different formats can be
merged into one. After, having the ontology implemented and populated, the ontology was dumped into a triple store (https://jena.apache.org/documentation/serving_data/Jena), so that users are able to query the ontology. Figure 6.1 shows the steps followed by the computer science students to implement and populate the ontology.

Figure 6.1: Ontology Implementation and Population Process

6.2.1 Validation of the Ontology

To be able to visualize the ontology, Protégé, an open source ontology editor from Stanford University (http://protege.stanford.edu/), was used. With Protégé it was easy to visualize the classes and properties of the ontology. As a reminder, the classes were all the nodes in the concept map which represented the indicators and its attributes. The object property was the link phrases used in the concept map. Figure 6.2 illustrated the list of the classes and object properties showed in Protégé. To better understand the ontology refer to the report Freight performance Measurement (Caballero et al. 2016). In this report all the programming process is described in more detailed.
Protégé showed the description of each indicator, including for example which indicator was a subclass of an indicator or a criterion, and the instances of each indicator. As shown in Figure 6.3, “Fatal Incident” was a subclass of “Incident” meaning that fatal incident is a type of incident. Instances are the result (occurrences) of the data. In this case there are two instances meaning there is a total of two fatal incidents.
Figure 6.2: Illustration of Protégé Class and Object Property (Caballero et al. 2016)
On every step in the process of implementing and populating the ontology, the computer science students and instructor consulted with us if the ontology was representing the correct information. Ontologies are traditionally evaluated using competency questions (Noy and McGuinness 2001). Competency questions are the questions that potential users of the framework will ask the knowledge base and are used to verify that the ontology is able to answer correctly and completely those questions.

6.2 Queries

6.2.1 Competency Questions

Competency questions were defined to evaluate the capability of the ontology to answer questions made by potential different to measure the freight system’s performance. These users include truck companies, MPO planners, TxDOT engineers, the public, and researchers. The initial six questions to evaluate the ontology are the following:
- **Trucking Company** - Which POE has the shortest average waiting time in 2014?
- **MPO Planners** - Does El Paso have congestion/day of more than or equal to 8 hours per day and 50% of the system congested?
- **TxDOT Engineers** - What is the ADT of the I-10 segment at Americas Interchange (near Don Haskins)?
- **Public** – What is the toll revenue per car at the Cesar Chavez Hwy at Fonseca?
- **Researchers** - How many accidents are there in I-10 at Hawkins?
- **Researchers** - How many accidents occurred during the morning peak hour (from 7:00 a.m. to 9:00 a.m.)?

### 6.2.2 Questions into Queries

To be able to answer these competency questions, queries were developed. A query is the method of requesting information from databases. SPARQL (Prud’hommeaux and Seaborne 2008) was the query language used to query the ontology to answer the questions. The questions mentioned in the previous section were developed into queries. The query statements and details may be seen in the ontology report Freight Performance Measurement (Caballero et al. 2016). The queries were done through a small simple web application developed by computer science students. The web application with the questions may be seen in Figure 6.4.
Freigh Performance Metrics Questions?

I. Which POE has the shortest average waiting time in 2014?
   [Query]

II. Does El Paso have congestion day of more than or equal to 8 hours and 50% of the system congested?
    [Query]

III. What is the ADT volume of the I-10 segment at Americas Interchange (Don Haskins Volume)?
     [Query]

IV. How many accidents are there in I-10 at Hawkins?
    [Query]

V. Toll Revenue per car? (Toll Revenue/ADT Volume at Cesar Chavez Hwy at Fonseca)
   [Query]

VI. How many accidents occurred during morning peak hour (7am to 9am)?
    [Query]

Figure 6.4: Query Web Application (Caballero et al. 2016)
7 Discussions

7.1 Collaboration

This research was an interdisciplinary collaboration between the civil engineering and computer science programs. The civil engineering team provided the domain expertise for the ontology, created the concept map and competency questions to evaluate the ontology. The computer science team was in charge of implementing and populating the ontology, creating a customized program for populating the ontology, and create a simple interface to query the ontology to answer the competency questions.

The civil engineering team looked for the data and made sure that the data was trustworthy and was responsible for designing the concept map. After the concept map was developed the civil engineering team provided the data sources, the semantics of the data retrieved from the data sources, including provenance containing the location of the data, units and how the data contributed to the indicators described in the concept map.

After the concept map had been completed, it was given to the computer science team to develop the ontology. The concept map embedded all the information needed to develop the ontology and populate the knowledge base. The computer science team and the civil engineering team worked very closely so the computer science team has all the data needed to develop the ontology and the product meet the needs of the civil engineering team. The computer science team developed the software needed to answer the competency questions. The technical details of the computer science team may be seen in the report Freight Performance Measurement (Caballero et al. 2016).
7.2 Challenges

The biggest challenge in this research was to find the data. Many indicators, although important, did not have data available or there was a budget or time constraint. Even though some indicators did have the data, another challenge was to determine the trustworthiness of the data. It was very important to have a trustworthy source as it may affect the credibility of the freight performance measurement scores. Users also need to feel confident with the source as important decisions may be being made when using this knowledge base.

Having data in different formats presented a challenge it is more difficult to integrate the data. In addition, some formats of the data were not able to be automated. For example, the traffic volumes that were provided by TxDOT in PDF format were not able to be automated so an Excel spreadsheet was created manually. This made it easier to parse the data and populate it into the ontology. For this research it was easy to manually enter the data but in a future this would be time consuming. It is important to find a way to automate the conversion of the format or find a way to upload the data in a more simple way. This may be part of future work which will be discussed in the next section.

7.3 Future Work

This research is just the first phase in the development of a practical, implementable freight performance measurement framework. The work stills needs to be continued as collaboration between civil engineering and computer science researchers so that this freight performance measurement framework could develop into something of value for potential users and decision makers.

In the future, it is essential to identify and integrate the data missing from our framework. Even though some data is not available now or being collected periodically, it could be collected...
by the civil engineering team in the field. However, doing so could be expensive, time consuming, and non-sustainable. That is the main reason that collection of missing data is not part of this research but is suggested for future work by the agencies.

Some users of the freight performance measurement framework may believe that some indicators are more important than others. It is important to validate the framework with different users to check if the framework, criteria and indicators are something they could use. It is important to develop an index that combines indicators. For example, traffic engineers may think that the speed indicators are the most important indicator while planners may believe that level of service is the most important indicator. This may be done by interviewing different users to understand which indicators each of them would use, and then using the analytic hierarchy process to determine the indicators’ weights for each user. This way the “Potential Users” column in the framework could be validated.

Another research question is how will this data be best presented to the users? How is the user interface going to look like? The example questions given in Chapter 6 are very simple and basic. It is important to have a user friendly user website for the user to make queries. An example of how it could look like could be seen in the website of Smart Cities Information System (http://smartcities-infosystem.eu/).

Another issue is who is going to keep the system with up-to-date data. This may be done manually or automated. This is a challenge because manual update could be time consuming and costly. The preferred way is to update automatically. The system developed has the capability of updating automatically the data as long as it is available on the web and overcome the challenges of having the data distributed and using heterogeneous formats. In the future, the task of
integrating data will be facilitated by the adoption of Open Data best practices by the different city agencies, in particular on the context of Smart Cities.
8 Conclusions

8.1 Summary of Research

This research has developed a comprehensive freight performance measurement framework. The framework consists of four criteria: safety, mobility, congestion, and environmental sustainability. Each criterion consists of several qualitative and quantitative indicators. A semantic approach using ontology has been proposed to integrate data that come from different sources, formats and updating frequencies. A concept map has been developed to better explain the relationships between the data and design the ontology. Queries were developed to evaluate the knowledge base developed. Combining freight performance data into a knowledge base based on the ontology makes it easier for users to be able to retrieve data, answer questions about the data and discover implicit links between the data and metrics.

8.2 Contributions

Freight performance measures have been recommended by FHWA to quantify the operating efficiency of the freight transportation system on existing infrastructures. Many agencies have been able to develop freight performance measures; however, methods to integrate the freight data from different sources and formats have not been demonstrated. The existing freight performance measurement frameworks just lists of performance indicators; none has divided the indicators into four criterions to better organize the data.

This research has demonstrated that ontology-based approaches can integrate heterogeneous and distributed data relevant to freight performance measurement, with the implementation of the first prototype of this framework. This research also contributes to the
collaboration between computer science and civil engineering. Working together made the integration of data easier and much more practical.

In this research a more comprehensive freight performance measurement framework has been proposed. This framework, with improvement, may be applied to any other city around the nation.
References


Vita

Eduardo J Torres was born in El Paso, TX. He graduated from the University of Texas at El Paso in 2014 with a Bachelor’s of Science in Civil Engineering and then completed his Master’s Degree in Civil Engineering in 2016. During his undergraduate studies he worked at the Border Intermodal Gateway (BIG) Lab as a research assistant under supervision of Dr. Kelvin Cheu. During his studies he worked in two internships with two different companies, Metropia and the City of Frisco. Eduardo was involved in different organizations during his student career. He was involved in Chi Epsilon, American Society of Civil Engineers (ASCE), and Institute of Transportation Engineers (ITE). He participated in the ASCE steel bridge team for two years. He was also the president of ITE during his las year of graduate studies. Eduardo was a recipient of the Dwight D. Eisenhower Transportation Fellowship during his two years doing his Master’s degree.

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