SOUTHERN PLAINS TRANSPORTATION CENTER

Web-Based Routing Assistance Tool to Reduce Pavement Damage by Overweight and Oversize Vehicles

HONGCHAO LIU, Ph.D., P.E.
SANJAYA SENADHEERA, Ph.D.
DAVONG WU, Ph.D.
JUNXUAN ZHAO, M.Sc.

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16. ABSTRACT

This report documents the results of a completed project titled "Web-Based Routing Assistance Tool to Reduce Pavement Damage by Overweight and Oversize Vehicles". The tasks involved developing a Web-based GIS routing assistance tool and evaluate the impact of OS/OW loads to highway pavements.

The objectives of this project are: (1) to analyze historical data with respect to the dimension and weight of the OW/OS vehicles, their origin and destination, permitted routes, and frequency of the routes; (2) to develop an electronic Origin Destination (OD) Matrix and a digitalized region wide Route Map on the basis of historical records; (3) to determine thresholds and design criteria for accommodating OW/OS vehicles and super-heavy loads; (4) to develop a desktop-based tool with integrated pavement and routing information; (5) to develop a web-based tool with integrated pavement and routing information; and (6) to develop pavement performance models by using the collected pavement condition data, traffic data, OW/OS vehicle data and environment data.

The product of this project will provide guidance on the criteria to design and maintain highway structure and pavement. The pavement performance models have laid a basis for other similar projects, i.e., developing an optimal routing algorithm to significantly reduce road damage from OS/OW vehicles. In addition, the web-based routing system provides valuable lessons for other states that are looking for such a website to solve OS/OW vehicles routing issues.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

Acknowledgements

WEB-BASED ROUTING ASSISTANCE TOOL TO REDUCE PAVEMENT DAMAGE BY OVERWEIGHT AND OVERSIZE VEHICLES

Final Report

October 2016

by

Hongchao Liu, Ph.D., P.E.
Professor
Department of Civil, Environmental, and Construction Engineering
Texas Tech University

Sanjaya Senadheera, Ph.D.
Associate Professor and Director, TechMRT
Department of Civil, Environmental, and Construction Engineering
Texas Tech University

Dayong Wu, Ph.D.
Postdoctoral Researcher
Department of Civil, Environmental, and Construction Engineering
Texas Tech University

and

Junxuan Zhao, M.Sc.
Research Assistant
Department of Civil, Environmental, and Construction Engineering
Texas Tech University

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INTRODUCTION

1. PROBLEM STATEMENT

Trucks that carry loads that exceed standard weight limits (80,000 lbs) and standard size (8 feet 6 inches wide and 14 feet high) are known as overweight and oversize vehicles, and trucks with gross vehicle weight (GVW) exceeding 254,000 lbs or maximum permissible weight on any axle or axle group, or 2,000,000 lbs with less than 95 ft. of axle spacing are defined as super-heavy loads [1]. The Motor Carrier Division (MCD) of the Texas Department of Transportation (TxDOT) issues permits to these types of vehicles. The MCD is responsible for ensuring that all highways, bridges and other structures along the route can accommodate the physical size and weight characteristics of the permit vehicle. To this end, traffic engineers in the office of MCD are continuously engaged in working to ensure that the routes are carefully selected such that the damages by these super-heavy vehicles can be reduced. They also work with other TxDOT departments in a team effort to ensure that the latest information, such as those regarding new construction and maintenance, be updated in a timely manner, and that the truck drivers be informed throughout the permitted route.

As the number of overweight and oversize (OW/OS) vehicles and the vehicle-miles of travel have increased over the past several years in Texas, the number of permits issued for OW/OS has increased considerably. According to the MCD's 2011 annual report (TxDOT, 2012), the number of OW/OS permits issued in FY 2011 increased 9% and 42% over FY 2010 and FY 2008 respectively, while the super-heavy permits increased 98% over FY 2006 and an astounding 337% over FY 2004.

The permitting process is a complex procedure that involves route validation based on the size and weight of the permit vehicle and the constraints and conditions of specified routes. Pavement conditions, bridge clearances, bridge live-load capabilities, roadway geometry, and temporary restrictions are important in determining routing feasibility. Traditional methods for generating and validating vehicle routes are manual and thus labor intensive. Permit routes are usually traced by hand over paper or computer-generated maps. Although computer-aided routing systems have been developed in recent years, there exists a gap between systematic evaluation of the impacts of super-heavy loads to pavement damage and a user-friendly tool to assist the route planning.

2. BACKGROUND

Efficient vehicle permitting and routing of oversize and overweight vehicles could significantly reduce road damage. An OW/OS load can cause damage to highways

in a number of ways including those shown in the following list. History has shown that it may only take one vehicle-pass for such failures to occur.

(1) Pavements with Asphalt Concrete as Wearing Course

- An axle load that exceeds the allowable limit can damage the pavement in rutting, shear failure in the pavement foundation layers and/or failure in the pavement surface.
- Tires of the vehicle transporting the OW/OS load travel close to the pavement edge, causing damage to the pavement including rutting, pavement edge failure, and road embankment slope failure.
- In the case of multiple super-heavy loads (e.g. loads generated by wind turbine farms), the number of equivalent single axle loads (ESALs) exceed the remaining life of the pavement.
- Pavement damage caused by the OW/OS load when transported at a time when the pavement is in a weakened state (e.g. soft asphalt concrete surface at high temperature and/or weak pavement soil foundation due to high moisture state.
- Turning movements cause vehicle tires to either move closer to the pavement edge or even outside of the paved area.

(2) Pavements with Surface Treatments as Wearing Course

- Pavements with surface treatments as the wearing course, which accounts for close to one-half of the total highway centerline miles under state control, may not have the structural capacity to carry super-heavy loads.
- Turning and braking movements on pavements with surface treatments as the surface can cause failure of the surface treatment including aggregate turning and delamination of the surface treatment from the base.

(3) Pavements with Cement Concrete as the Wearing Surface

- Excessive wheel load can cause cracking of the pavement slab.
- Punch-out failure of continuously reinforced concrete (CRC) pavement can occur.
- Failed or unsupported joint area of a slab can cause failure.

The majority of the existing routing systems are GIS-based or web-based visual tools that show the level of capability and indications for the road pavement maintenance.

(1) GIS-Based Routing Systems
Generating vehicle routes requires access to databases systems storing information about pavement, bridges, construction, roadway geometry, and signs. Routing also necessitates network optimization procedures, and specialized geo-processing functions such as address geo-coding. GIS systems traditionally provide these functions as resource-intensive desktop systems. A typical GIS-based OW/OS vehicle routing system currently in use is Wisconsin DOT's system [2]. This system was designed primarily for the application in Wisconsin's two major freight corridors

rather than aiming at statewide implementation. It includes a bridge evaluation program that automatically evaluates bridge capacities, a data model that interfaces Wisconsin DOT's main database with the system, and a route searching engine that creates optimal routes based on the shortest-path principle. The core of the system is the routing algorithm that interacts with a GIS tool (ArcInfo) and a database management system (Oracle-based) to produce feasible routes.

(2) Web-Based Routing Systems

Web-based permitting systems combine traditional GIS functions with database-storage technologies and decision-modeling tools, allowing decision makers to manage large volumes of spatial data and to provide visual feedback in the form of online digital maps. In a web-based routing system, all decision-support related operations are performed on a network server. One of the recently developed web-based permitting systems is DelDOT's Spatial Decision Support System (SDSS) [3]. In the system, the origins and destinations for permit vehicles are described using street addresses, interstate mile markers, and street intersections. These locations were validated and geo-coded with the locations of bridges and other structures of interest, such as toll-booths and road signs. Highway assets and their characteristics are maintained in DelDOT's main database. The individual database systems were integrated into a centralized special database that provides information for the routing algorithm to generate and validate feasible routes.

3. OBJECTIVES

The objectives of this project are:
(1) to analyze historical data with respect to the dimension and weight of the OW/OS vehicles, their origin and destination, permitted routes, and frequency of the routes.
(2) to develop an electronic Origin-Destination (OD) Matrix and a digitized region wide Route Map on the basis of historical records.
(3) to integrate pavement data and the projected damage by OW/OS vehicles into the database and visualize the information on the digital map.
(4) to develop a GIS-based (i.e., desktop-based) tool with integrated pavement and routing information.
(5) to develop a web-based tool with integrated pavement and routing information.
(6) to develop pavement performance models by using the collected pavement condition data, traffic data, OW/OS vehicle data and environment data.

4. SCOPE

This research project aims to develop a web GIS-based routing assistance tool to optimize the OW/OS routes based on the historical and expected heavy traffic levels and pavement conditions. Another main goal is to evaluate the impact of OW/OS loads to highway pavements by analyzing historical data with respect to the

characteristics of OW/OS vehicles, their origin and destination, permitted routes, frequency of the routes, pavement condition data, and climate effect.

Recently, extensive studies have been made nationwide to develop load-zoning procedure and methods for evaluating load restrictions. However, these studies did not lead to applicable methods that can be used to evaluate the impact of super-heavy loads and to determine new design criteria and strategies for maintenance. There are no documented guidelines and recommendations that provide practical guidance on appropriate parameters and preservation techniques specifically developed for accommodation of the OW/OS loads. To this end, the proposed approach in this project is valuable for states with the GIS-based pavement management system looking for a workable solution to assess their mass historical OW/OS routing data, and evaluate the OW/OS loading impacts to their infrastructures.

A traditional thick-client based routing-application supporting system was developed using Visual Basic and ArcView 3.0 [4]. This research project offers two kinds of routing systems: one is a desktop-version and the other is a web-version. Both have user-friendly interfaces and are easy to use. Especially for the web-version, users can browse the routing system through the website instead of installing the software.

BODY

1. ROUTING ASSISTANCE TOOL DEVELOPMENT

In this project, the researchers put their major efforts into developing two routing assistance tools with integrated and pavement information: one is the GIS-based (i.e., desktop-based) tool and the other is web-based tool.

1.1 GIS-Based Routing Tool

After comparing several GIS development platforms, either open-source or commercial, MapSuite from ThinkGeo was determined to be the most suitable and powerful one. The desktop-version user interface design is based on the MapSuite software. It is a GIS-based assistance tool to achieve geo-analysis functions and provide road pavement models to predict the impact of OW/OS vehicles. In this project, the researchers mainly used the MapSuite desktop edition software by C# language. It is a .NET native set of GIS software controls that lets .NET developers add rich, interactive maps to their Windows desktop applications. Featuring both WPF and Winforms controls, packed with powerful mapping features and support for the most popular data formats, MapSuite desktop edition makes GIS accessible to developers of any skill. The researchers also used a routing extension to achieve the routing functions such as finding the shortest path from A to B, delivering turn-by-turn directions, avoiding specified areas and so on. The introduction of this GIS-based routing tool is as follows:

1.1.1   Login Interface

Figure 1. Login Interface

The first step for users to use this system is to enter account name and password in order to log into the system. Different groups of users, e.g., DOT staffs, truck drivers, system administrators, etc., are given different levels of permission and rights due to the concern of safety and varying needs. The login interface is shown in Figure 1.
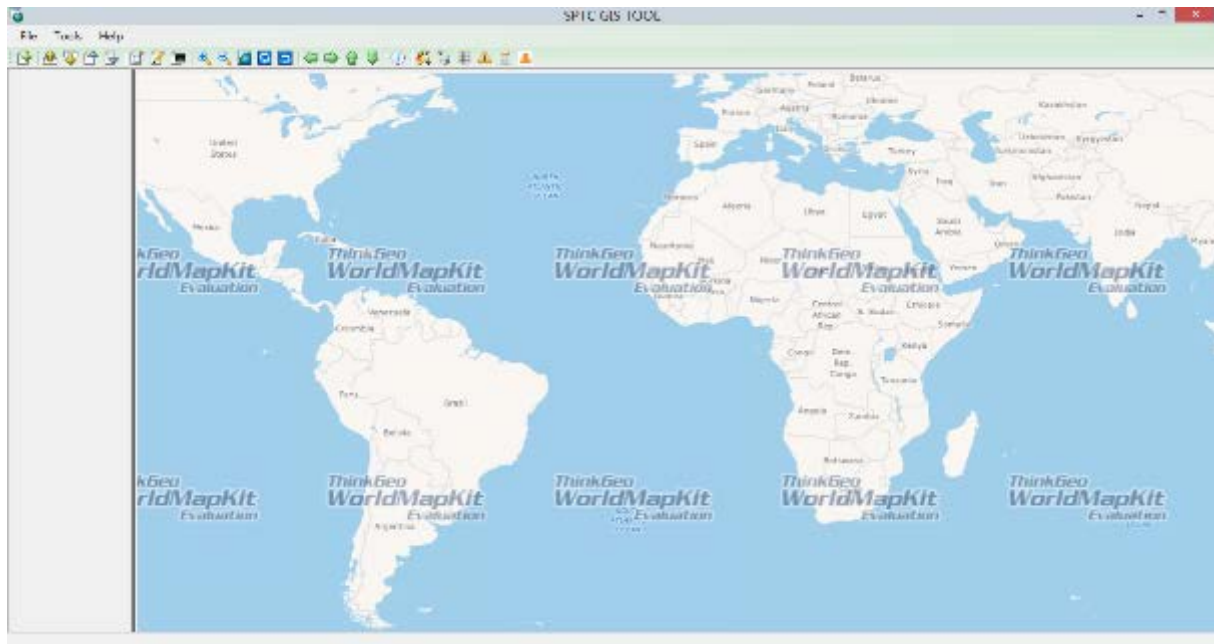
1.1.2 Main Interface

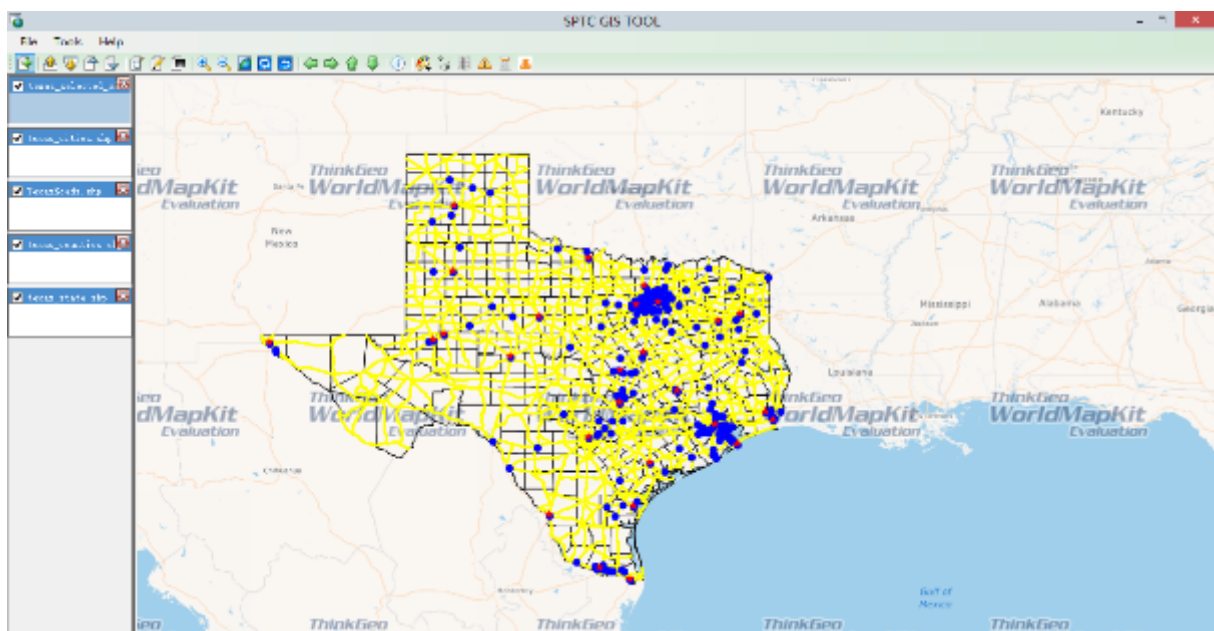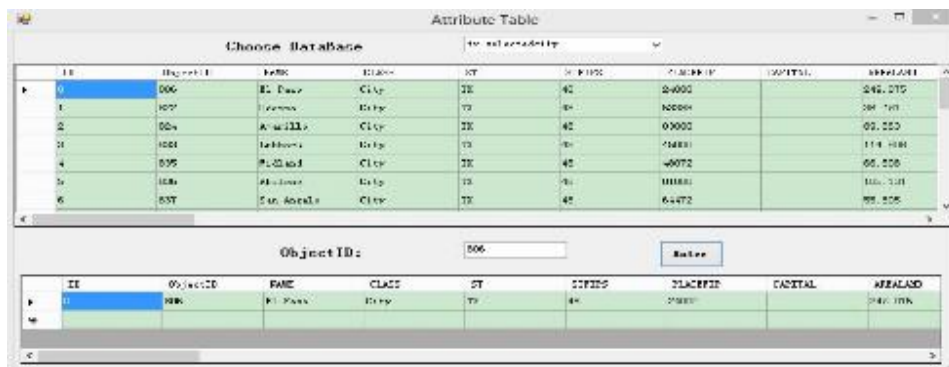**Figure 2. Main Interface (Desktop-version)**

Figure 3. File Operation

Figure 4. Related Information

The background map of the main graphical user interface (GUI) is retrieved from OpenStreetMap, which creates and distributes free geographic data for the world (Figure 2). The main function of this interface is to represent the image of every shapefile.

• Add the file operating functions: loading, adding, deleting GIS shapefiles (Figure 3).
• Add the GIS file view functions: zoom in; zoom out; pan left, pan right, pan up, pan down, full extent, toggle extent, previous extent.
• Style Editor: background color, change the styles of area, line, point and text.
• Order of shapefiles: move up, move down, mover to top, move to bottom.
• Information: show the data from related attribute table of the shapefile (Figure 4).
Users can use the main interface like ArcGIS desktop software. Add and view the shapefiles, show the information in the attribute table, and edit the symbol styles.

1.1.3 Database Interface

Figure 5. Database Connection

There is a basic MySQL database module in the GIS-based routing tool, which can view, search and update the data in the attribute table dynamically. Users could obtain specific data by entering the ObjectID. The data in the database will change according to the user interface at the same time (Figure 5). For example, when users choose the tx_selected table (i.e., tx_selected shapefile) first and enter the ObjectID (806), the system will show all information about the selected city. If the value for one specific field or column is changed, the data in the database will be changed accordingly.

1.1.4 Routing Interface
• Find the shortest path
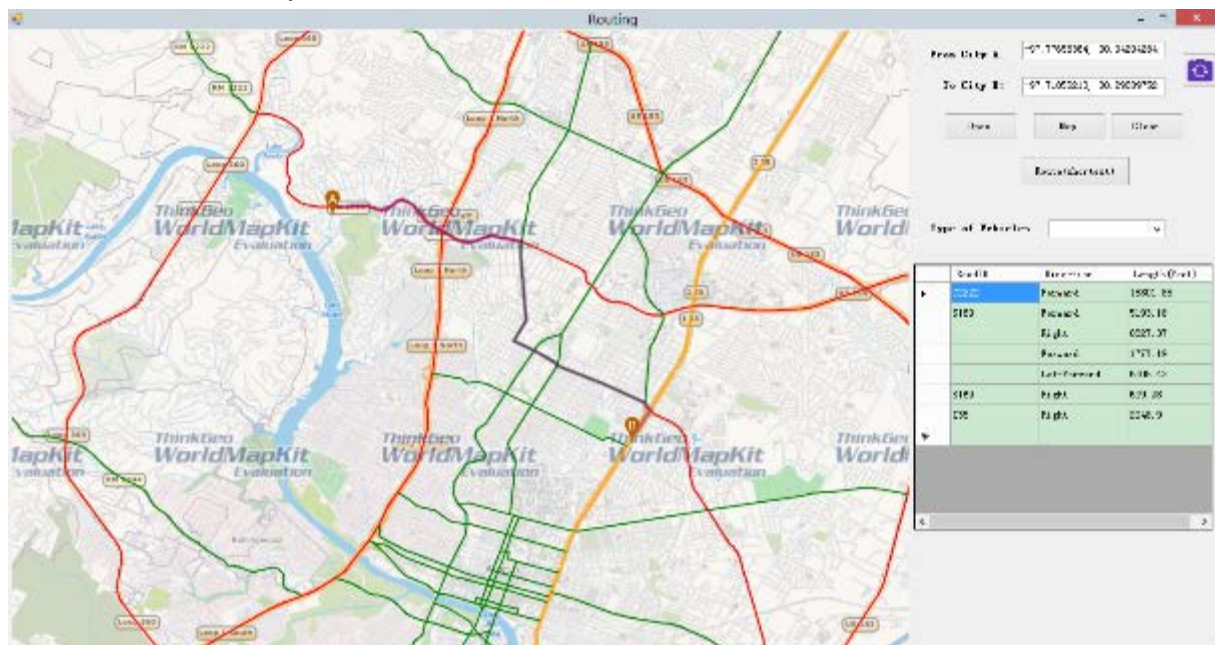
Figure 6. Shortest Path

Users can click the Open button to find the shapefiles that need to be displayed, then click the Map button to show the map associated with the selected shapefiles. They can click on the map to set starting and ending points (or switch the starting and ending points by clicking the switch button) and obtain the shortest route by clicking the Route(shortest) button. Users can show the latitude and longitude information of origin and destination and the turn-by-turn information (Road ID, Direction and Length) of the finding route. The clear button is used for clearing all the routes in the map and the corresponding information (Figure 6).

- Find the path according to the types of the vehicles
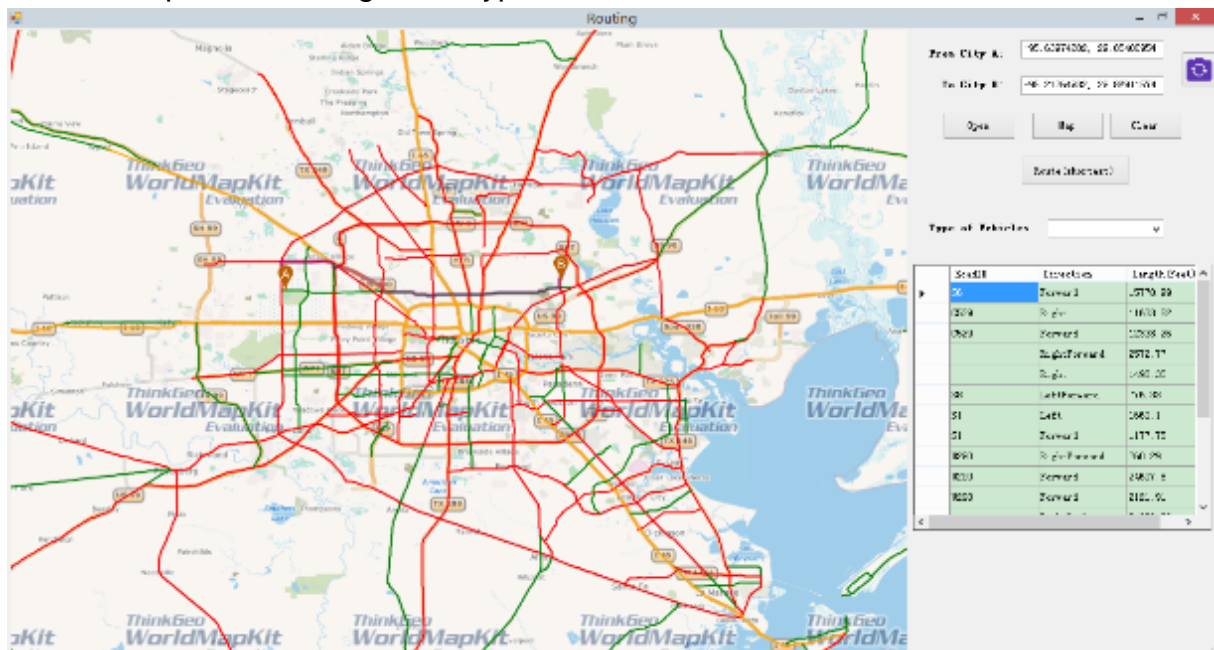
Figure 7. Shortest Path without Considering Pavement Condition
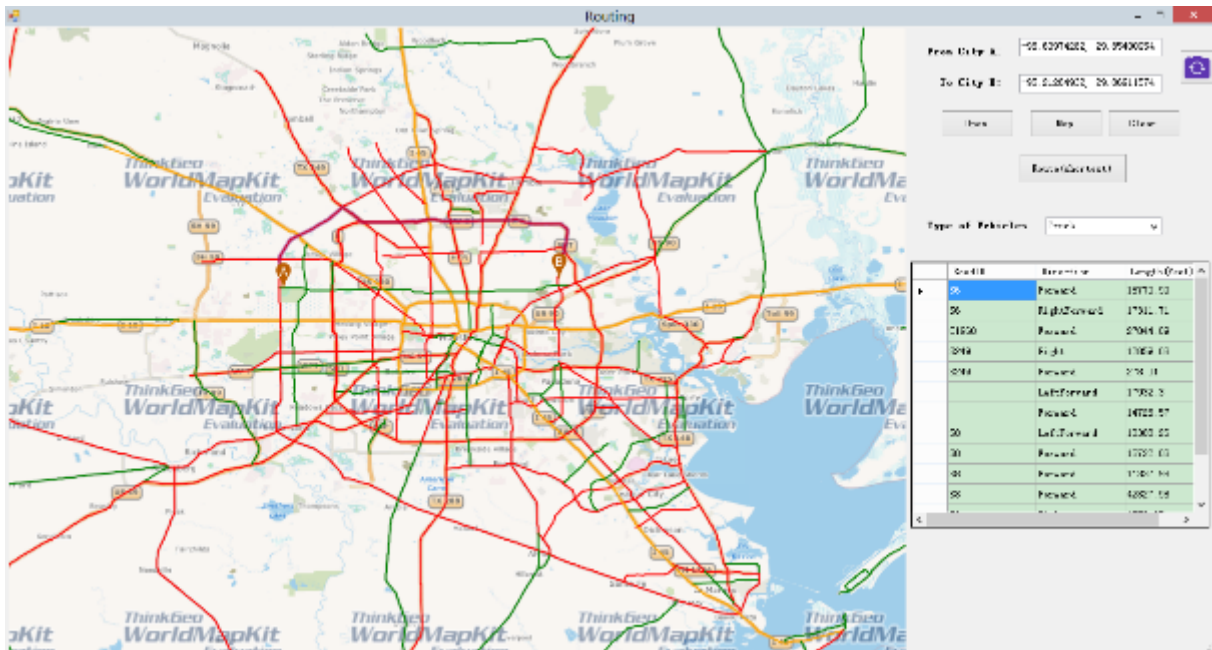
Figure 8. Truck only path (Red only)

Users can make routing decisions based on the conditions of road segments and the types of vehicles. For this prototype, the road segments are divided into three groups according to pavement condition (Good, Fair and Poor) and also are illustrated in three color lines (Green, Orange and Red) in the map. Vehicles are divided into three types according to their loads and sizes (Large, Middle and Small), that is, Truck, Bus and Car. Road segment group and vehicle type are in a one-to-one relationship. Figure 7 shows the routing decision between A and B without considering pavement condition, while Figure 8 presents the new routing decision between A and B with consideration of pavement condition. The selected vehicle type is heavy vehicle (e.g., Truck) for both cases.
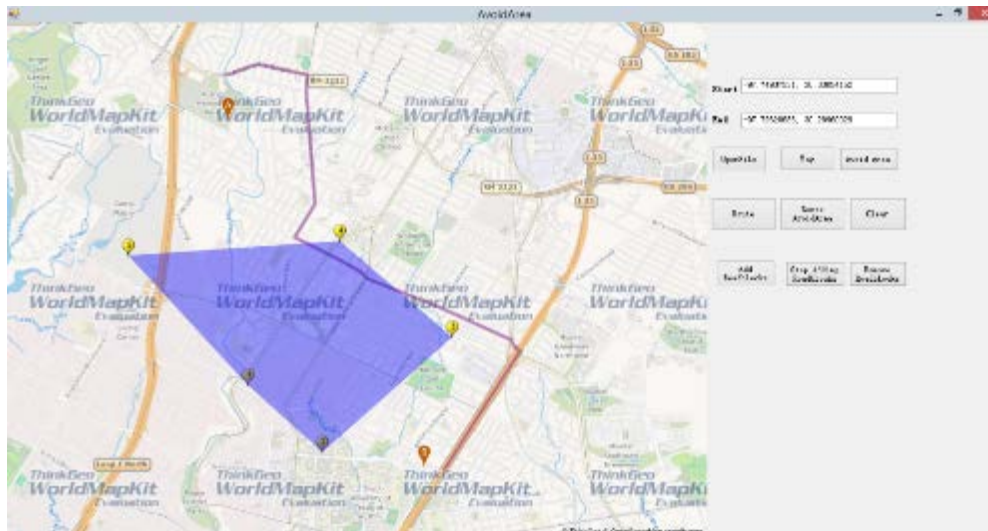
1.1.5 Avoid Area

- Avoid certain area

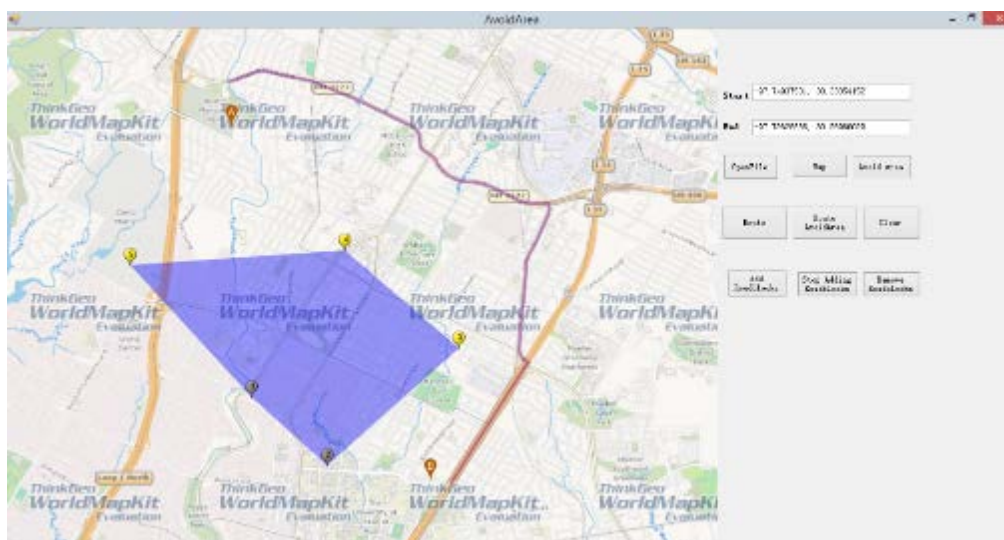**Figure 9. Shortest Path (Area)**

Figure 10. Avoid Area Path

Users can specify certain areas (e.g., school zone) to avoid when making routing decisions. The area can be any polygon as long as users specify the vertexes of the area. Figure 9 shows the routing decision between A and B without avoiding certain areas, that is, the shortest path, while Figure 10 presents the new routing decision between A and B while avoiding a specific area.
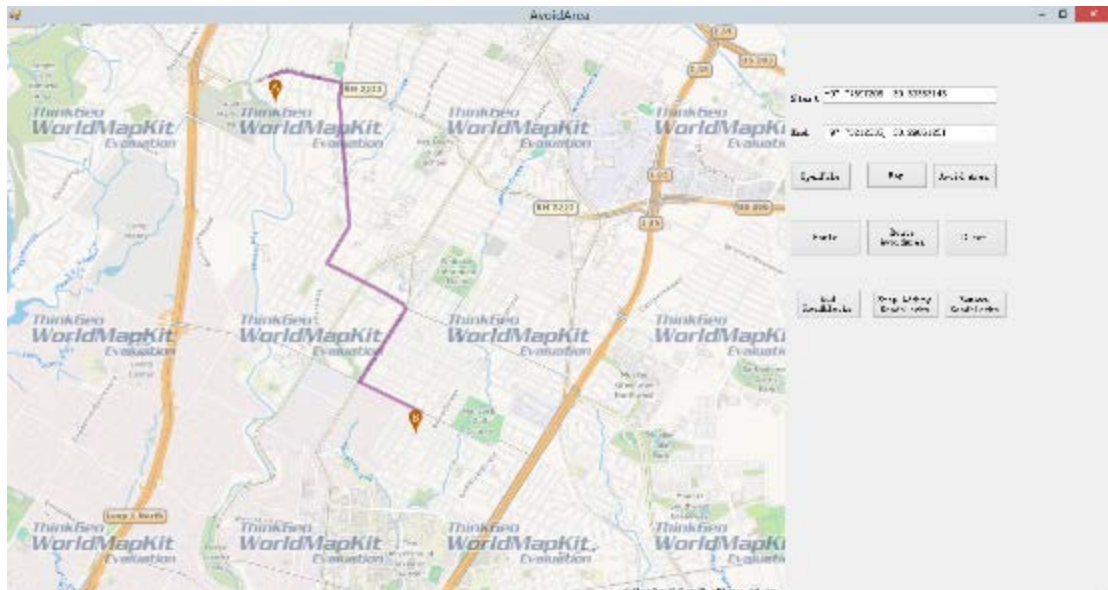
- Avoid specific road

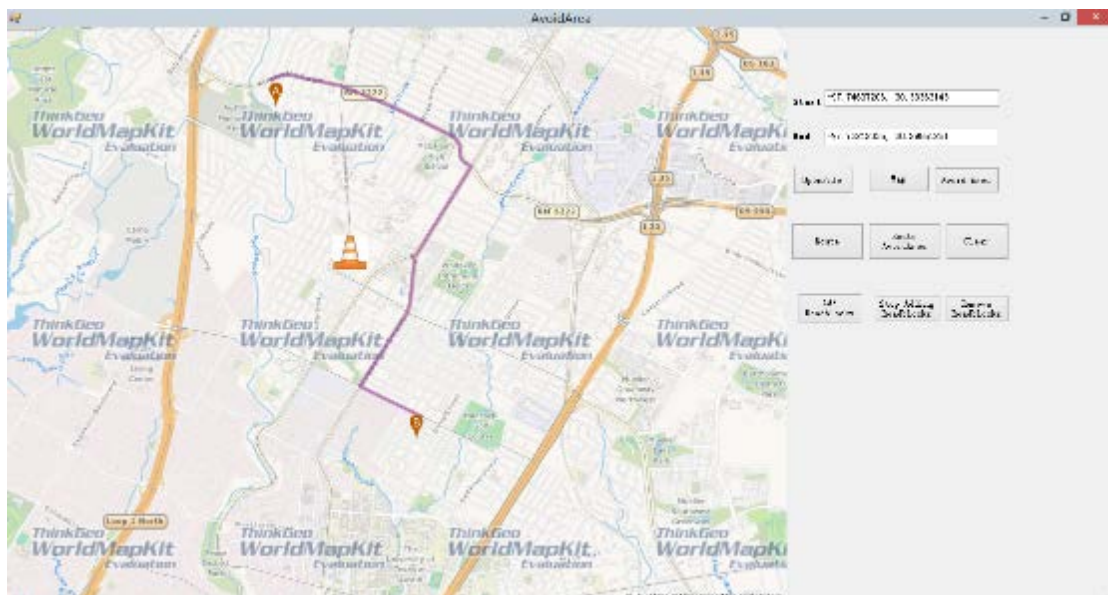**Figure 11. Shortest Path (Point)**

Figure 12. Add Roadblock Path

Users can specify certain points (e.g., barrier or accident) by adding roadblocks to avoid when making routing decisions. Figure 11 shows the routing decision between A and B without avoiding a certain point, that is, the shortest path, while Figure 12 presents the new routing decision between A and B while avoiding certain point.
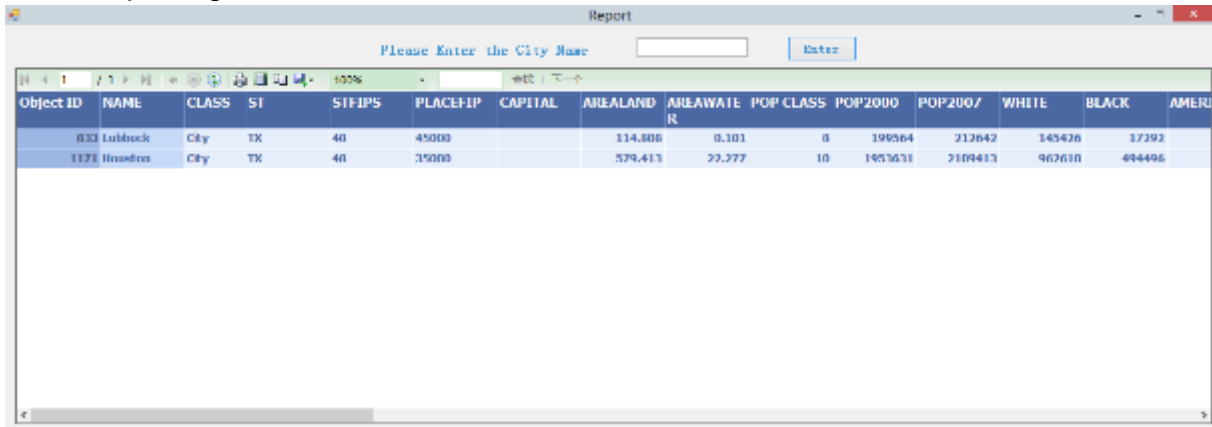
1.1.6 Reporting

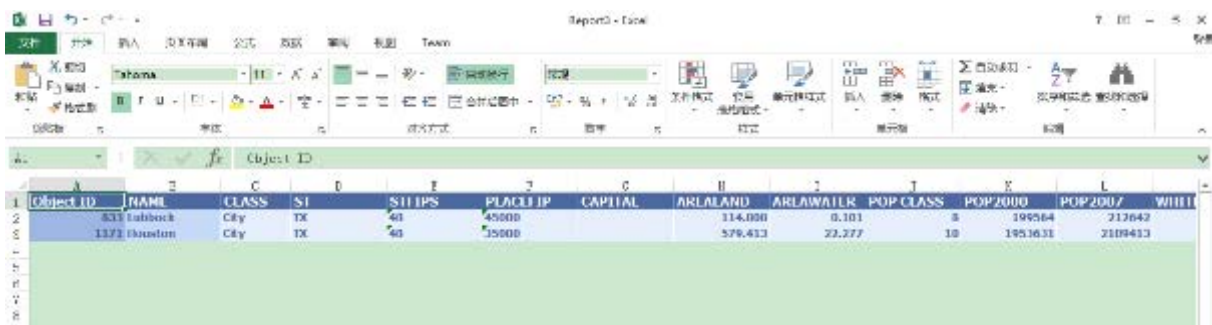
Figure 13. Report Interface

Figure 14. Excel File

The reporting function enables the GIS tool to generate a report from the database by entering the city's name and saving it as an Excel, Word, or PDF file, as shown in Figures 13 and 14.
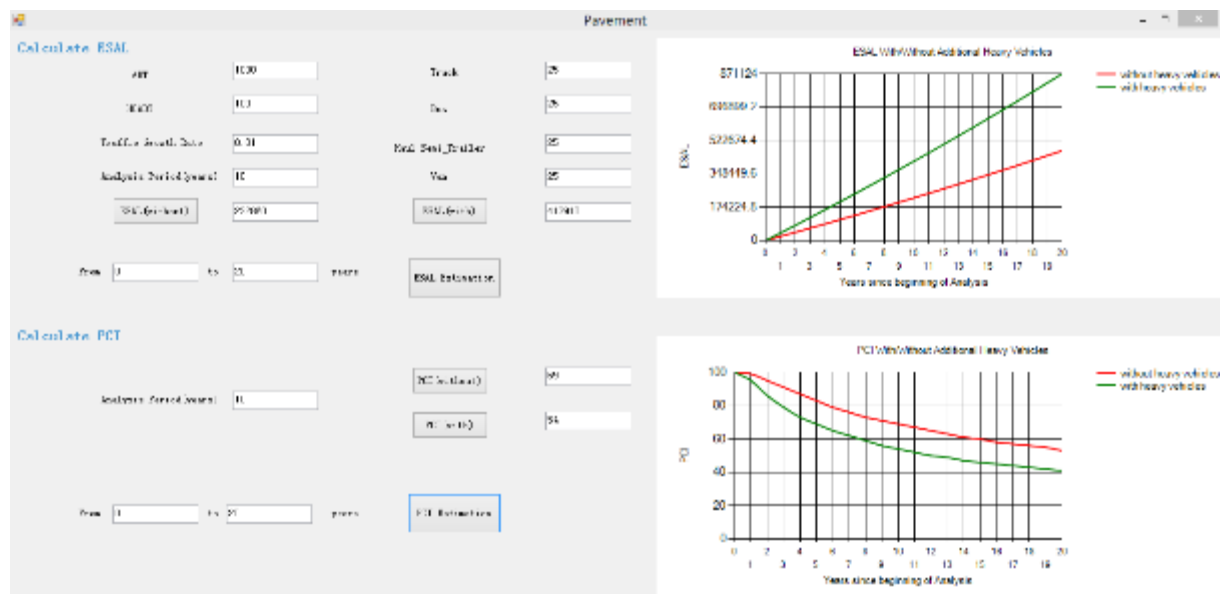
1.1.7 Heavy Vehicle Impact Projection

Figure 15. Pavement Estimation Interface

By integrating the developed pavement performance models, this feature can easily project the future condition of the pavement with or without the impact of heavy vehicles, which is shown in Figure 15.

- ESAL (Equivalent Single Axle Load)
a. ESAL Calculation
   Users enter ADT (Average Daily Traffic), HCADT (Heavy Commercial Average Daily Traffic), which is equal to the sum of four types of heavy vehicles (Truck, Bus, Haul Semi_Trailer and Van), traffic growth rate and analysis period (years) to calculate the ESAL with/without additional heavy vehicles for the specific year.
b. ESAL Prediction
   Users enter a time period (e.g., 0 to 20 years) to obtain the estimated ESAL with/without additional heavy vehicles for that period.

- PCI (Pavement Condition Index)
a. Calculate PCI
   Users enter a specific year to calculate the PCI with/without additional heavy vehicles.
b. PCI Prediction
   Users enter a time period (e.g., 0 to 20 years) to obtain the estimated PCI with/without additional heavy vehicles for that period.

1.2 Web-Based Routing Tool

The web-based routing tool is based on the ArcGIS Web AppBuilder (WAB), JavaScript, and HTML5/CSS3. The Web AppBuilder for ArcGIS (Developer Edition) provides extensible framework for developers to create custom widgets and themes. It also has some ready-to-use widgets such as query, geoprocessing, print and so on. The main functions of the web-based routing tool are described as follows:

1.2.1 Main Interface

Figure 16. Main Interface (Web-Version)

Figure 16 shows the main interface of the web-based routing system. Users can click the "+" or "-" buttons to zoom in or zoom out the map. Users can find their current location by clicking the "My Location" button. Clicking the "Home" button will show the map last used before the user logged out. The system also provides information about current map scale and the location of points (latitude and longitude). There is a search box for users to key in the location they are interested in.
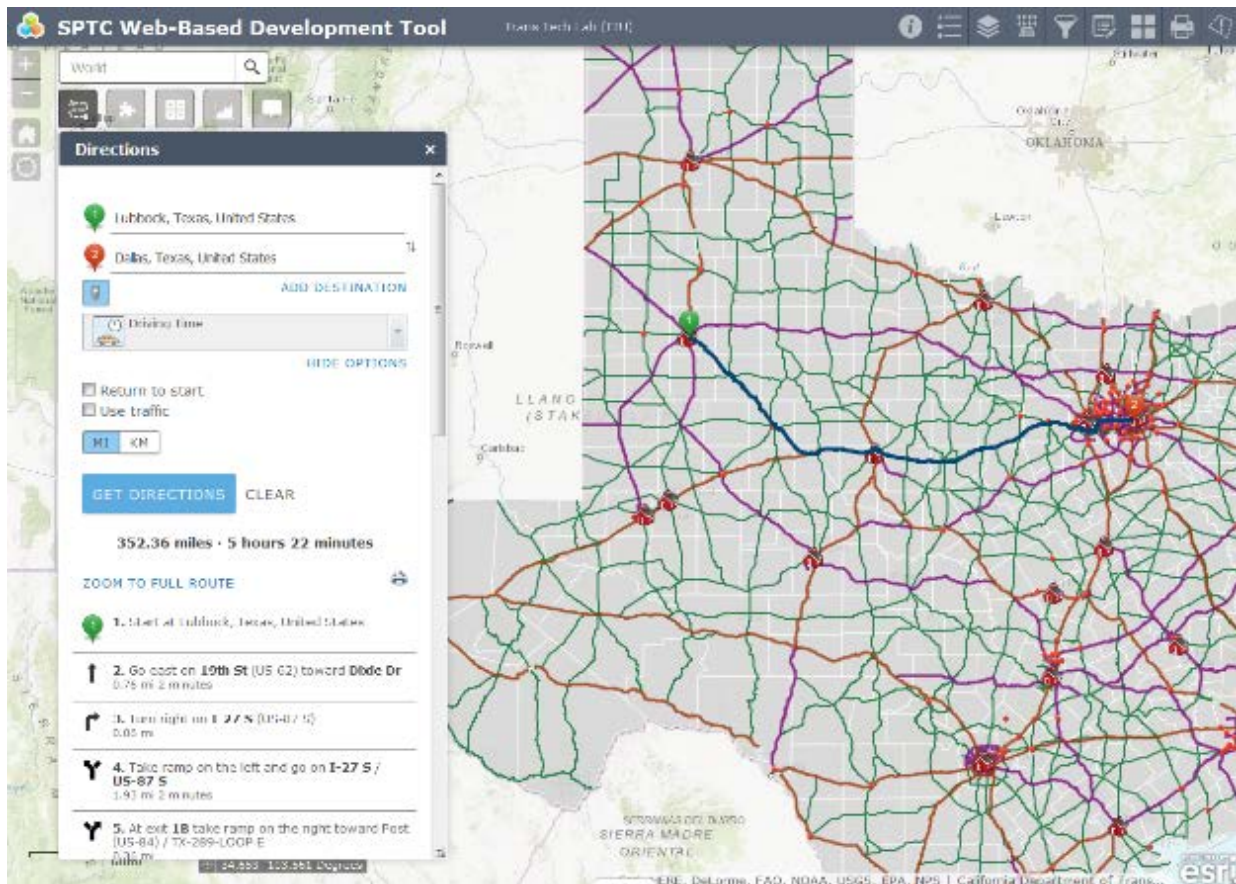
1.2.2 Directions

Figure 17. Directions

The basic function of the Direction widget is to provide a quick and efficient method of calculating the turn-by-turn directions between two or more locations (Shown in Figure 17). Users can specify origin, stop and destination by entering the name of the location, by clicking on the map to set a pin, or by using the current location. The printable finding route provides turn-by-turn information (Road ID, Direction and Length) and driving time. Checking the "Use Traffic" option will consider the real-time impedance from a traffic service when calculating the least-cost path between two destinations. Users can toggle between MI (Miles) and KM (Kilometers) to change the distance's units. The "Return to Start" option calculates directions from the last destination to the first destination automatically. The system also provides different travel modes such as the fastest/shortest and car/truck routes.
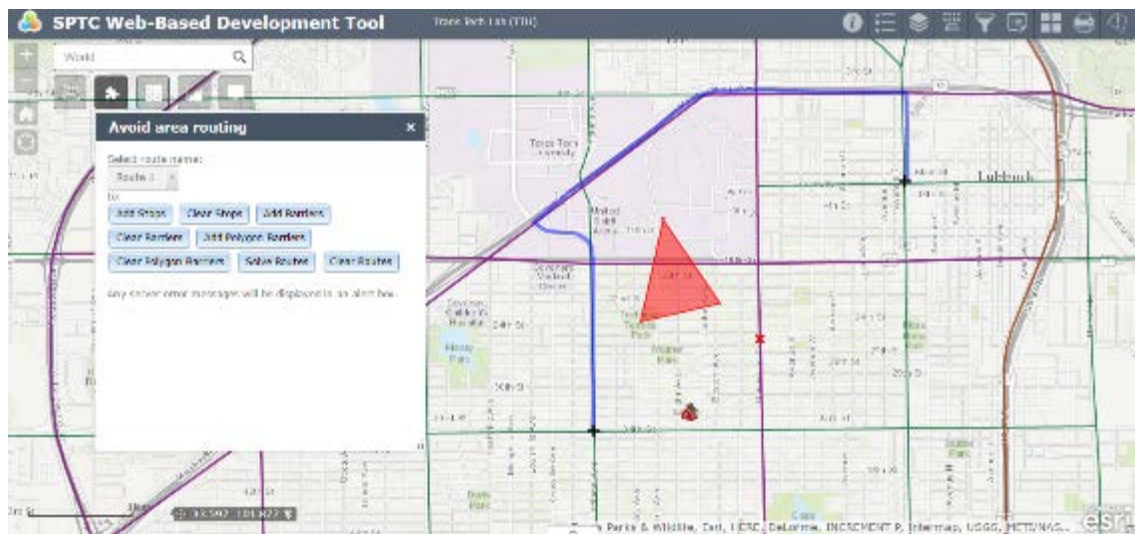
1.2.3 Avoid Area

Figure 18. Avoid Area

The Avoid Area Widget routes both with and without avoiding certain barriers and areas (shown in Figure 18). In default, users can find the shortest route between points A and B. If there is an accident (a barrier/a point) or a school area (an avoided area/a polygon) where heavy vehicles cannot go through, the routing feature will provide an alternative route automatically to avoid the barrier or the blocking area. It should be noted that users can create multiple barriers or avoided areas in one routing task, which is seen as a major upgrade from the GIS-based version.
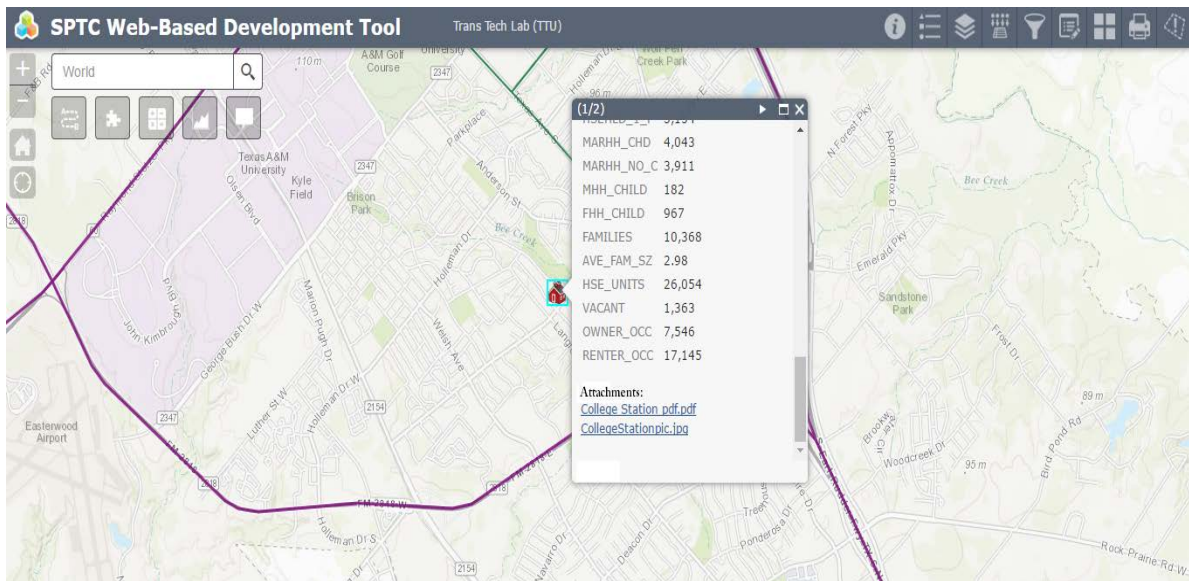
1.2.4 Editing

Figure 19. Editing

The edit feature provides geo-editing capabilities when using an editable GIS layer in a feature service. It has the following three major functions: (i) users can select an existing feature to view or update its geometry and attributes. Note that the administrator can specify which attributes are editable or not editable for users; (ii) users can add new features to the editable layer and edit their attributes in the associated attribute inspector. The corresponding items in the attribute table will be updated as well; (iii) users can upload, view and delete attachments (e.g., PDF, JPG, Doc, Excel, etc.) if the feature layer supports attachments. The example of this function is shown in Figure 19.
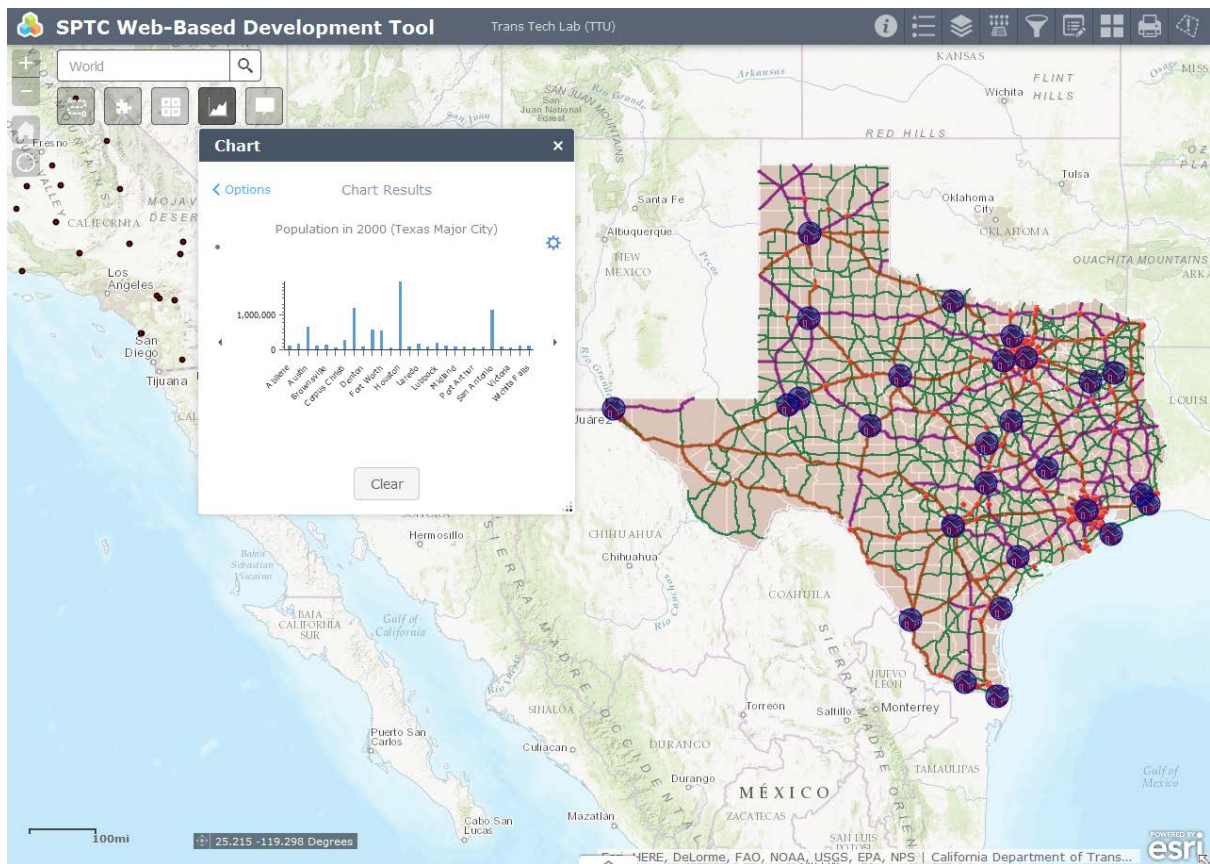
1.2.5 Chart

Figure 20. Chart

The Chart widget displays quantitative attributes from a feature layer in the current map as a graphical representation of data. The widget makes it easier for the users to observe possible patterns and trends from raw data. A chart can represent the attribute values of a single field, aggregated values for multiple fields, or the total counts for features. A bar or column chart can even represent the attribute values of multiple fields as clustered bars and columns. In addition, the users can specify a spatial filter to request only desired features to be in the chart. The chart type can be

bars, lines, and pies. Figure 20 shows the population in Texas major cities in Year 2000.
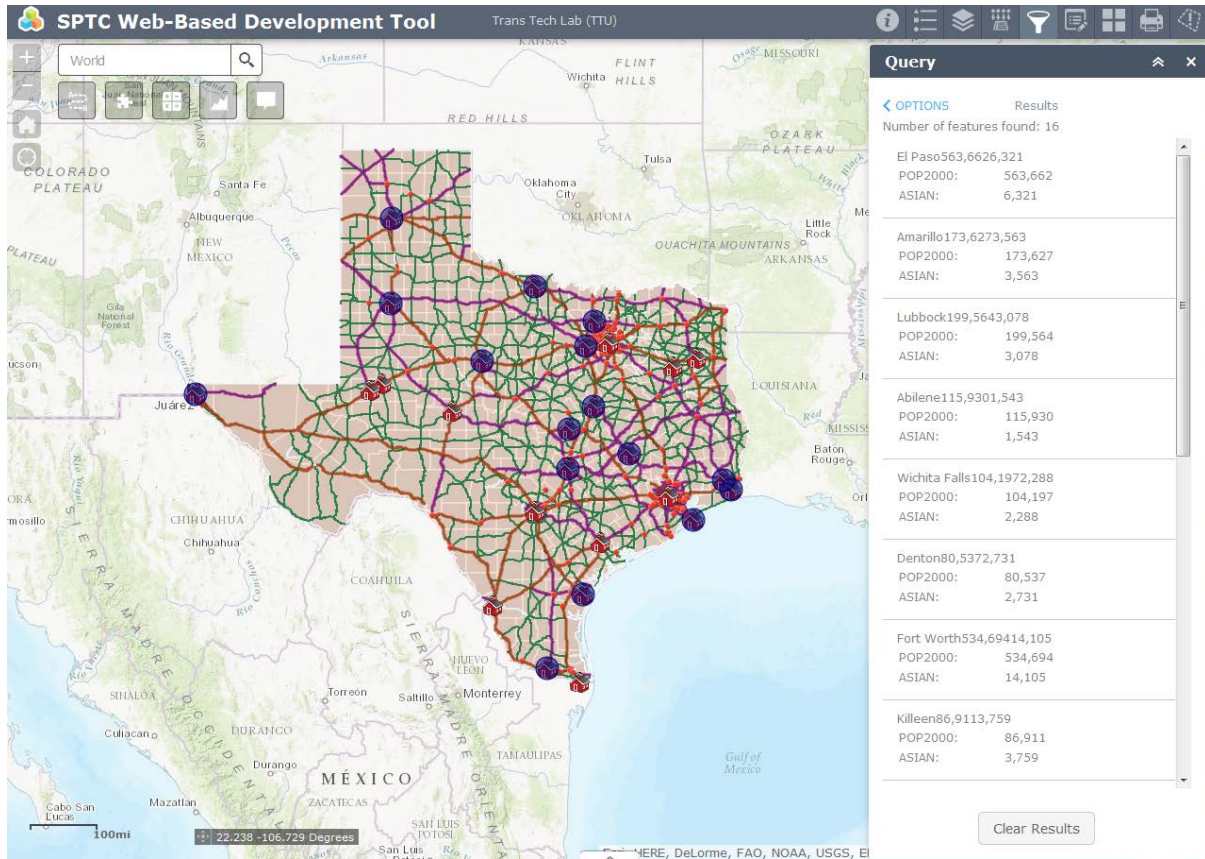
1.2.6 Query

Figure 21. Query

The Query widget allows users to retrieve information from a feature layer in the current map by executing a predefined query. Users can define the query by specifying the feature layers, filters and displaying fields in query results. Figure 21 shows the query results for the question that the population is less than 1,000,000 and Asian population is greater than 1,000 in Year 2000 for the Texas major cities.

1.2.7 Add Shapefile

Figure 22. Add Shapefile
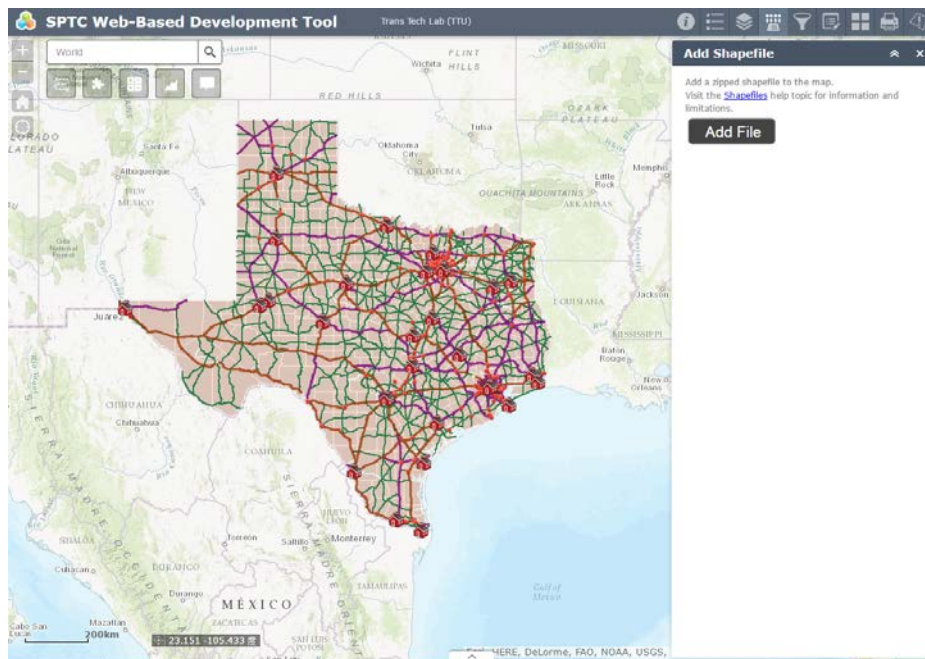
The Add Shapefile widget enables the users to add other (zipped) shapefiles to the current map and the new shapefile can be saved in the map. Figure 22 shows the interface of this function.
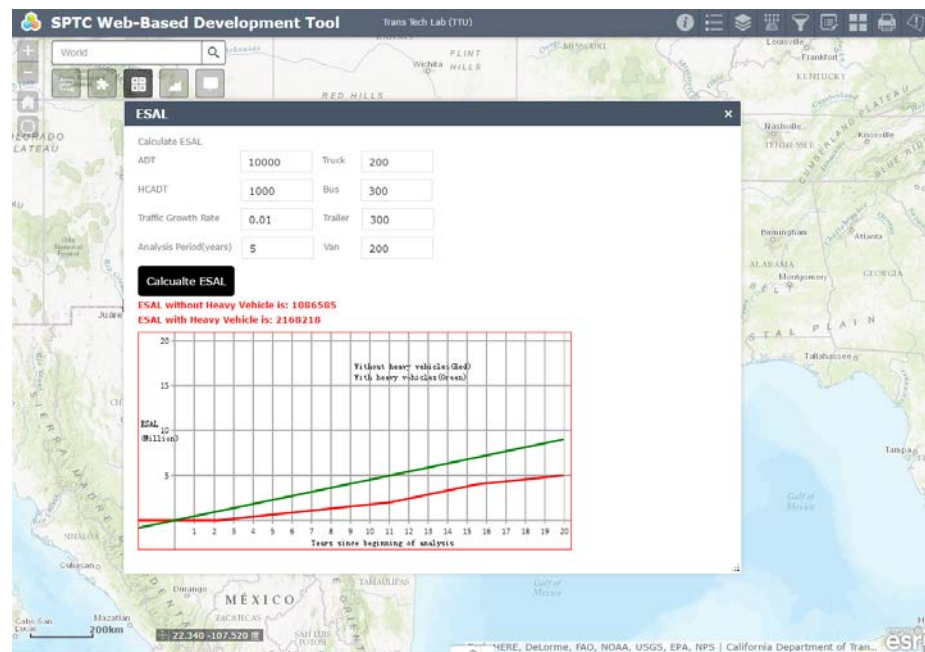
1.2.8 ESAL

Figure 23. ESAL

The main functions of this widget are to calculate ESAL with/without additional heavy vehicles for a specific year and give an estimate of ESAL with/without additional

heavy vehicles for a specific time period. Users enter ADT, HCADT, which is equal to the sum of four types of heavy vehicles (Truck, Bus, Haul Semi_Trailer and Van), traffic growth rate and analysis period (years) to calculate the ESAL with/without additional heavy vehicles for the specific year. Users then enter a time period (e.g., 0 to 20 years) to obtain the trend for the ESAL in the future. Figure 23 shows an example of calculating and estimating the ESAL.

1.2.9 PCI
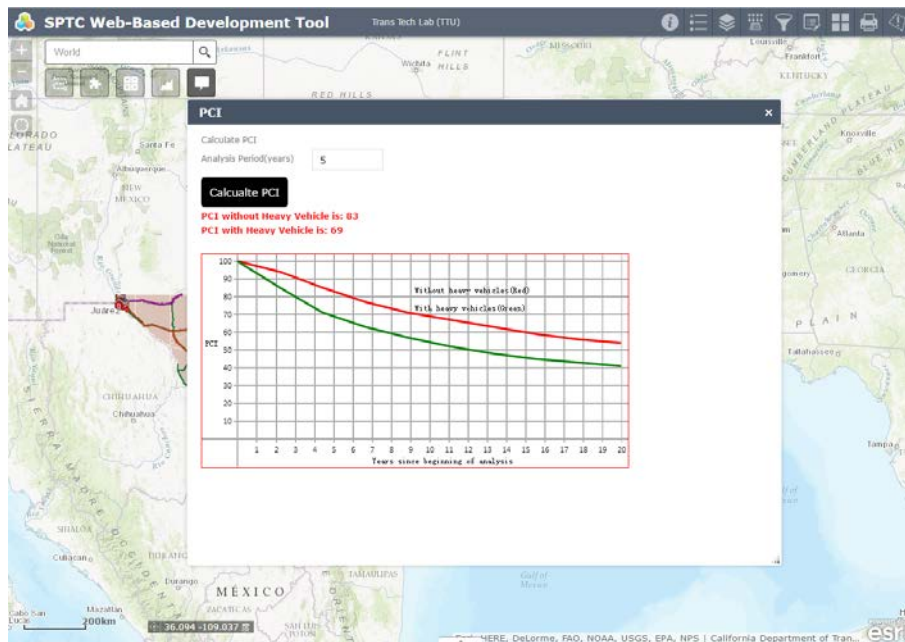
Figure 24. PCI

The main functions of this widget are to calculate PCI with/without additional heavy vehicles for a specific year and give an estimate of PCI with/without additional heavy vehicles for a specific time period. The only parameter that users need to enter is the specific year. Figure 24 shows an example of calculating and estimating the PCI.

1.2.10 About

Figure 25. About

The About widget creates content that displays in the widget. The content can be text, images, and hyperlinks. Figure 25 shows the basic information about this SPTC project.

1.2.11 Basemap
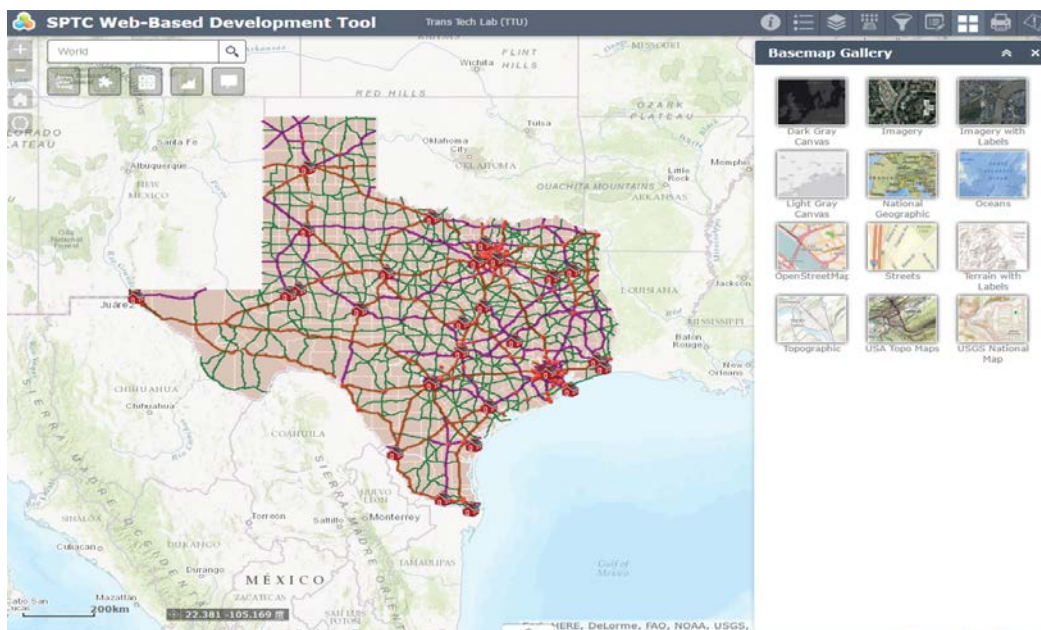
Figure 26. Basemap

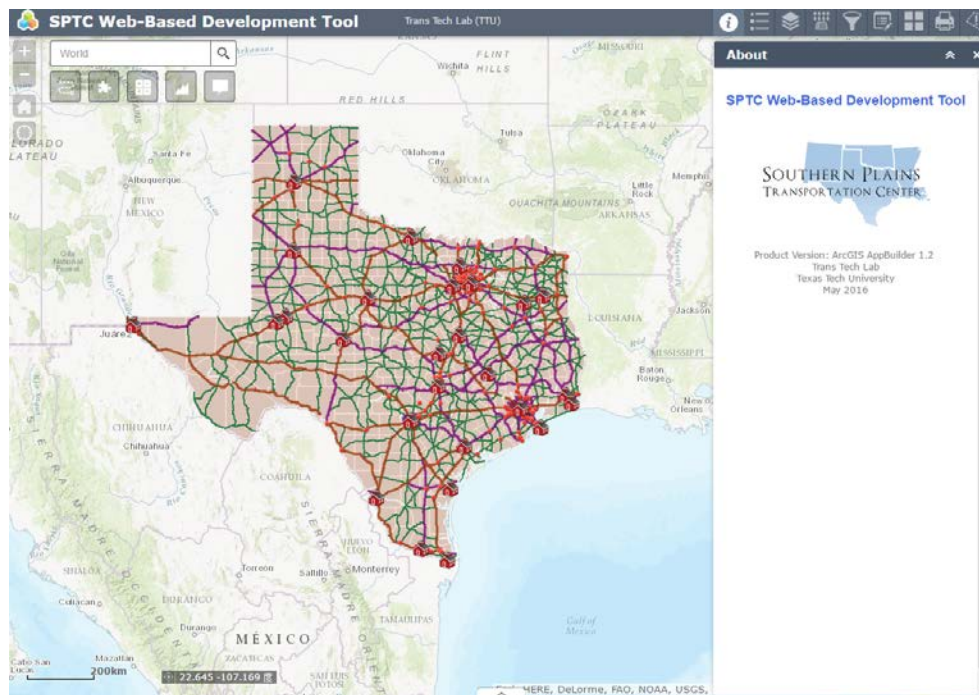The widget presents a gallery of base maps and allows users to select one from the gallery as the system's base map (shown in Figure 26). The base maps can be user-defined or from the users' organization or portal. It should be noted that all the base maps added to the Basemap widget must have the same spatial reference.

1.2.12 Print
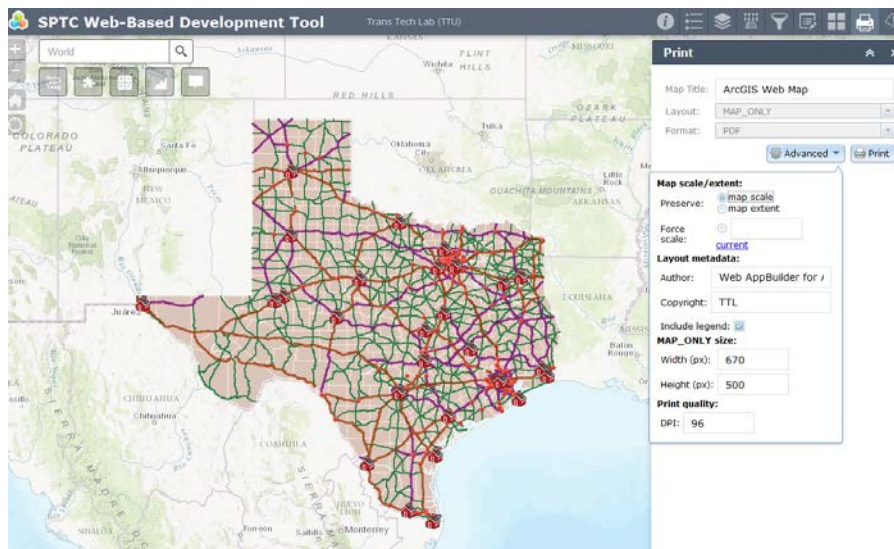
Figure 27. Print

The Print widget connects the web application with a printing service to allow the current map to print. Users can specify the title, author, copyright, format, layout and print quality of the map, as shown in Figure 27.

1.2.13 Attribute Table
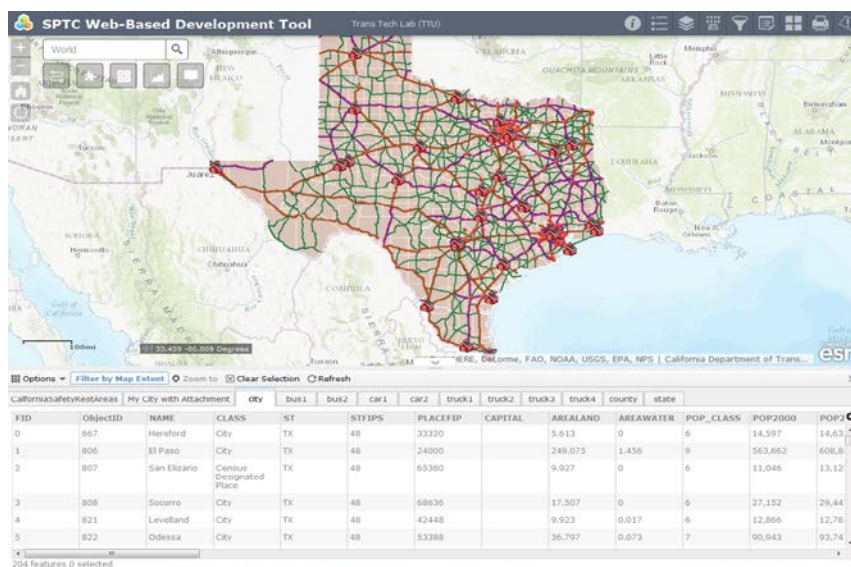
Figure 28. Attribute Table

The Attribute Table widget displays a tabular view of the feature layers' attributes. The widget displays at the bottom of the main interface and can be opened, resized,

or closed. When more than one layer's attributes display, multiple tabs automatically generate in the attribute panel, allowing users to switch among the attribute tables (Shown in Figure 28). In addition, users can filter the records in the attribute table, show the selected records, and export them to a CSV file.

1.2.14 Situation Awareness
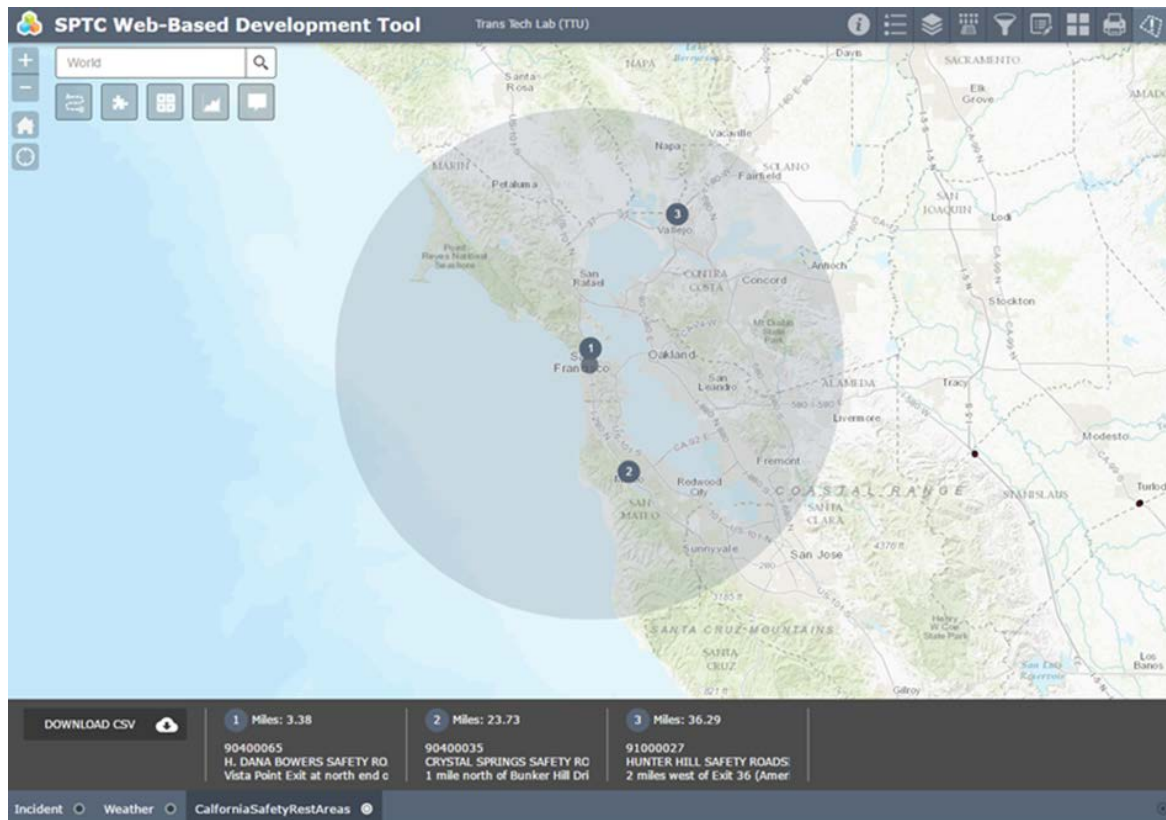
Figure 29. Situation Awareness

The Situation Awareness widget allows users to locate an incident on the map and analyze information from different feature layers within a specified incident area. The specific incident can be a point, a line or any polygon, and the incident area is measured by a buffer; users can specify the buffer distance. This widget provides related information around incident location within the incident area. The "Weather Options" also displays current and forecasted weather conditions at the incident location. Figure 29 shows the safety rest areas around San Francisco; this information was not available for Texas at the time of this report.

2. OW/OS LOADS IMPACT EVALUATION

2.1 Procedure

For this project, another goal was to evaluate the impact of OW/OS loads to highway pavements by analyzing historical data with respect to the characteristics of OW/OS vehicles (i.e., dimension and weight), their origin and destination, permitted routes, frequency of the routes, pavement condition data, and climatic effects. This evaluation included: 1) finding the impacts of different levels of OW/OS loads to highways in different climate zones; and 2) quantifying the parameters of the deterioration models for pavements under such circumstances for determining new design criteria and strategies for accommodating the OW/OS loads.

2.1.1 Data Consolidation

The evaluation of pavement damage caused by the OW/OS operation requires detailed information about pavement structures and materials, maintenance and repair (M&R) histories, OW/OS traffic characteristics, and regional climatic conditions. In this project, researchers used Pavement Management Information System (PMIS) as the major source for collecting the pavement data of the highways of interest. The dataset contains more than two million records that cover the entire state-network pavement data from 2004 to 2014. TxDOT divides each highway into a number of sections with an average length of 0.5 mile for pavement management and data collection purposes. In total, more than 190,000 data collection sections are contained in PMIS, which are identified (or referenced) by a unique address – a combination of district name, county name, highway name, and beginning and end reference mile markers.
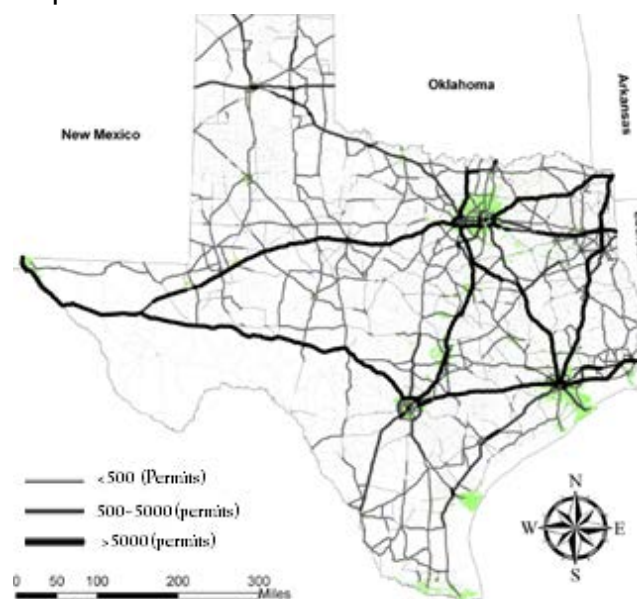
2.1.2 OW/OS Routes Map

Figure 30. Routes Map

In this project, we used the OW/OS map from a previous research project in Texas [5]. As part of that project, the researchers developed a highly efficient GIS-mapping approach and converted a massive data set of OW/OS permit routes into GIS format.

Figure 30 shows the most common roadways assigned to OW/OS loads in Texas [5].

2.1.3 Climate Zone
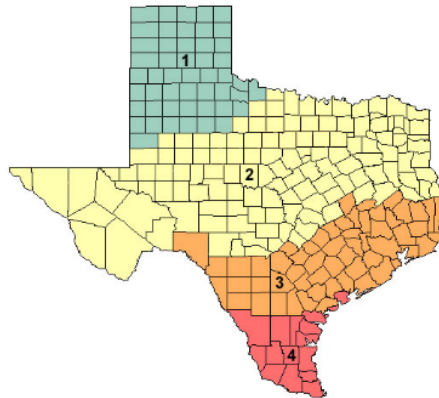
Figure 31. Climate Zone

Temperature and moisture affect pavement performance, and hence its capacity to accommodate the OW/OS load. For example, the OW/OS load may cause pavement damage when it is transported at a time when the pavement is in a weakened state. In consideration of this, we divided Texas into four zones as follows (Shown in Figure 31) [6]:

- Zone 1: This zone represents dry-cold climate.
- Zone 2: This zone represents dry-warm climate.
- Zone 3: This zone represents wet-cold climate.
- Zone 4: This zone represents wet-warm climate.

2.1.4 Methodology

In this study, we used Pavement Condition Score (PCS) as the primary pavement performance index, which is a 1 – 100 index (with 100 representing no or minimal distress and roughness) defined by TxDOT in the PMIS. PCS considers the pavement's Distress Score (DS) and roughness (measured in International Roughness Index or IRI). According to PCS, roads can be grouped into five classes: Very Good (90-100), Good (70-89), Fair (50-69), Poor (35-49), and Very Poor (1-34) [7]. The function for the regression under the combined effects of these factors is [8] [9]:

$$PCS = 100 - 100e^{-\left(\frac{a}{Age}\right)^{b}} \qquad (1)$$

Where PCS = Pavement Condition Score defined by TxDOT

Age = Pavement Age

a and b are two parameters that represent the effects of the considered factors

2.2 Case Study

In this project, we designed three case studies to evaluate pavement performance in different OW/OS scenarios and combinations of the related factors. In Case Study 1, we considered only the highways with the same OW/OS loading level, but in different climate zones. In Case Study 2, we put our focus on the highways in one climate zone (Zone 2) only and studied their performance at various OW/OS traffic levels. In Case Study 3, we made a further analysis on the reduction of pavement service life for the highways selected in Case Study 2.

2.2.1 Case 1: The impact of OW/OS vehicles on highways in different climate zones
• The High OW/OS Traffic Scenario

Figure 32. PCS in Case 1 (High OW/OS)

Table 1. Regression Coefficients in Case 1 (High OW/OS)

Climate Zone	Selected Road	Road Section	Parameter a	Parameter b
Zone1	US287L	122-278	15673.0012	0.0651
Zone2	US287L	278-394	5254.8034	0.0939
Zone3	US90R	692-922	35.0825	0.2000
Zone4	US77L	710-814	50.6585	0.2057

In this scenario, we selected one highway in each climate zone, which are: US287L (Zone1), US287L (Zone2), US90R (Zone 3), US77L (Zone4). Noted the selected roads are in the same class to ensure that they have similar pavement characteristics (materials and structures, for example) at the maximum extent. Their pavement performance curves were regressed, as shown in Figure 32. The regression coefficients are summarized in Table 1.

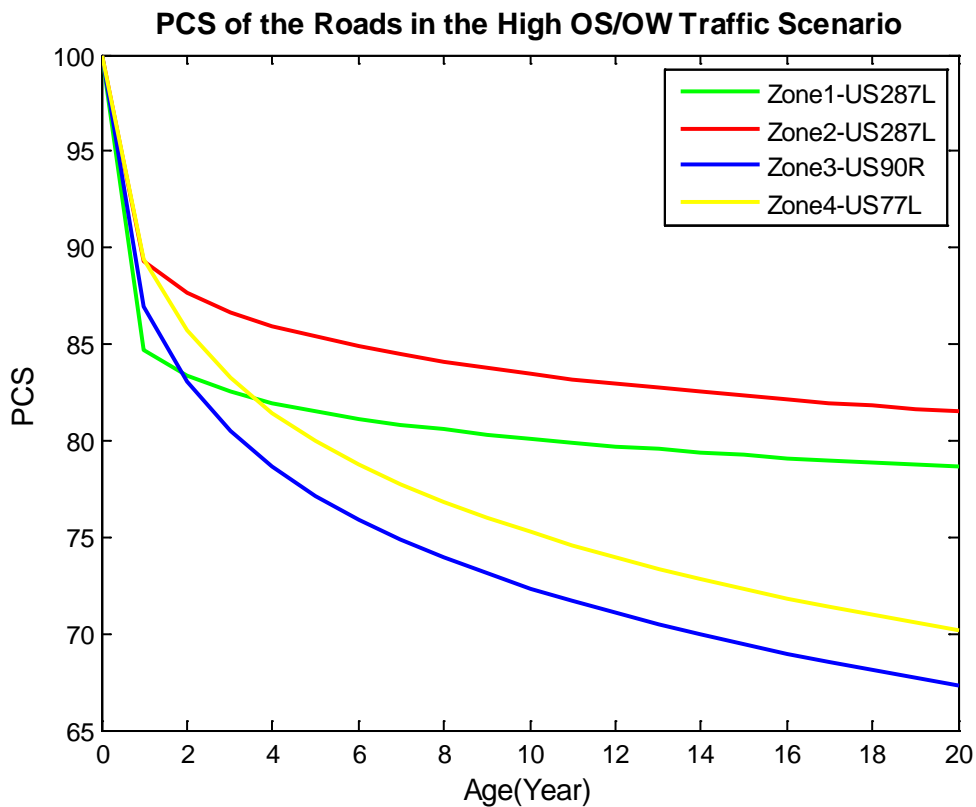• The Low OW/OS Traffic Scenario
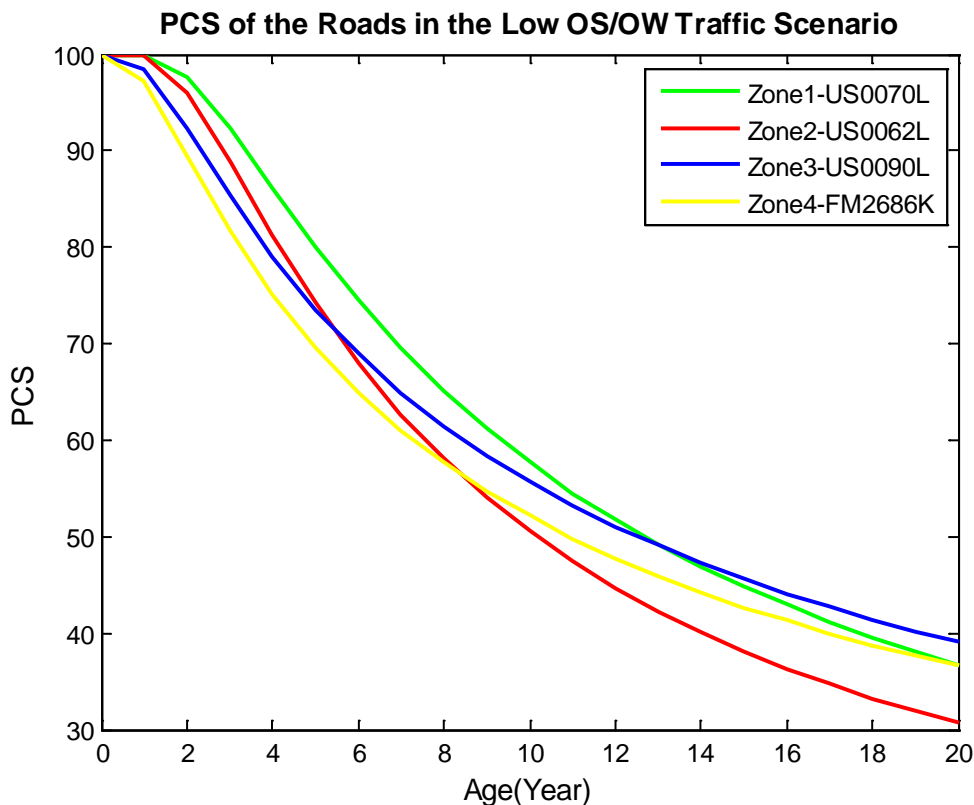
Figure 33. PCS in Case 1 (Low OW/OS)

Table 2. Regression Coefficients in Case 1 (Low OW/OS)

Climate Zone	Selected Road	Road Section	Parameter a	Parameter b
Zone1	US70L	226-480	8.4662	0.9087
Zone2	US62L	24-136	6.8977	0.9450
Zone3	US90R	422-484	7.4720	0.7123
Zone4	FM2686K	474-492	6.4260	0.6912

In this scenario, similarly, we again selected one road in each climate zone, which are US70L (Zone 1), US62L (Zone2), US90L (Zone 3), FM2686K (Zone 4). It should be noted that in Zone 4, we had to choose an FM class road due to the limited data. The pavement performance curves were regressed, as shown in Figure 33. The regression coefficients are also summarized in Table 2.

2.2.2 Case 2: The impact of OW/OS vehicles on highways in the same climate zone
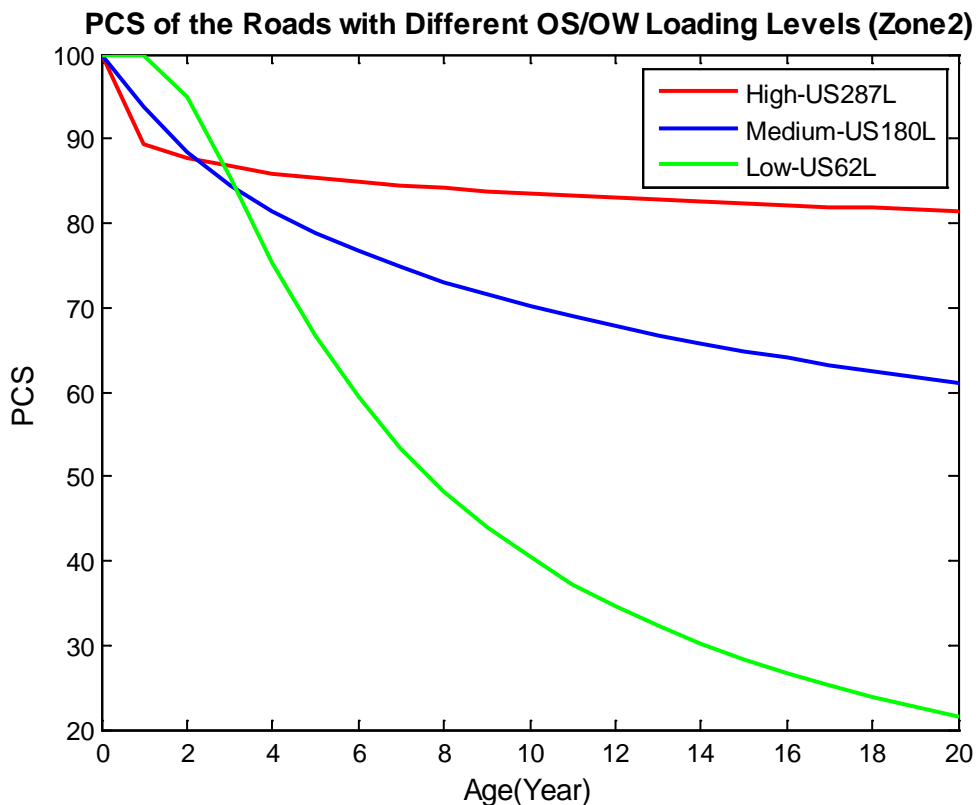

Figure 34. PCS in Case 2

Table 3. Regression Coefficients in Case 2

OW/OS	Selected Road	Road Section	Parameter a	Parameter b
High	US287L	278-394	5254.8	0.0939
Medium	US180L	506-554	17.0104	0.3595
Low	US62L	24-136	5.4550	0.1089

In this case study, we put our focus on Zone 2 only and studied the roads with different levels of OW/OS loads in the same climate zone. We divided the OW/OS loading into three levels: High, Medium and Low. Next, we selected one road at each level: US287L (High), US180L (Medium), US62L (Low). Note that the selected roads are in the same class to ensure that they have similar pavement characteristics (materials and structures, for example) at the maximum extent. The performance curves of these roads were regressed and illustrated in Figure 34. The regression coefficients are summarized in Table 3.

2.2.3 Case 3: The pavement service life reduction at various OW/OS loading levels

In this case study, we made a further analysis to investigate the pavement service life reduction at various OW/OS loading levels. Note that the OW/OS load level on a highway is measured by accumulative ESALs. In this case, we divided the OW/OS loading into four levels:
- Extreme OW/OS Loading: greater than 1,000,000 ESALs per year
- High OW/OS Loading: between 200,000 and 1,000,000 ESALs per year
- Medium OW/OS Loading: between 20,000 and 200,000 ESALs per year
- Low OW/OS Loading: less than 20,000 ESALs per year

Correspondingly, we selected four highways based on the Texas OW/OS vehicle routing map, which are: US 337 (Low), US 62 (Medium), US 87 (High) and US 180 (Extreme). ΔLife (%) denotes the road service reduction percentage. For example, ΔLife (%) is equal to 0% for a new road (or the road service life is 100% at this point). As time goes by, the accumulative ESALs on this road will be increased, and so will the reduction of service life (ΔLife (%)). We chose a basic exponential function to regress the relationship between the pavement service life reduction versus pavement age, as shown in Equation 2:

$$\Delta Life\ (\%) = a * (Accumulative\ ESAL)\ {}^{\wedge}b + c \qquad (2)$$

Where: *a*, *b* and *c* are regression coefficients that we need to find.
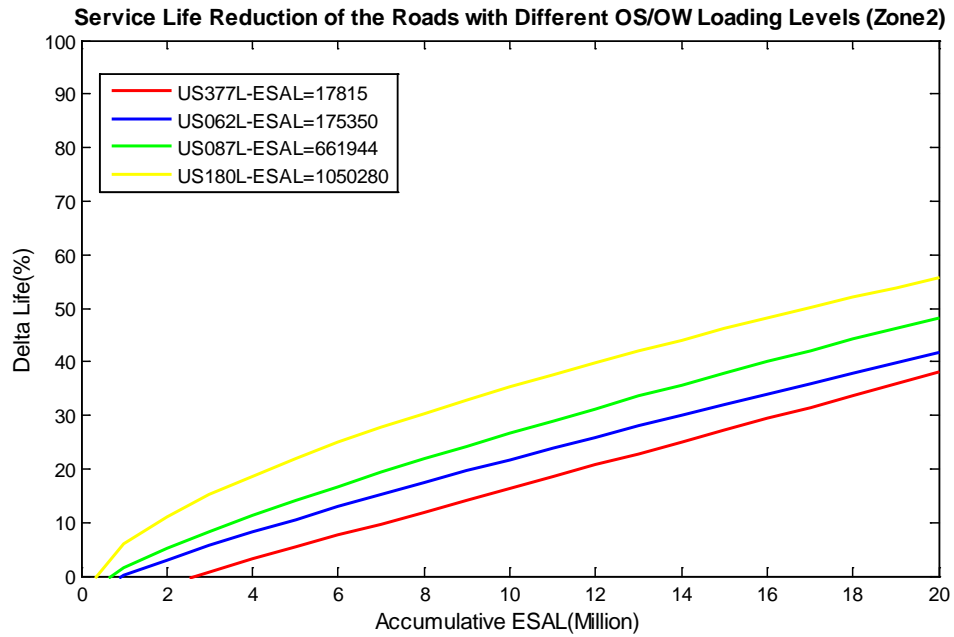
Figure 35. Road Service Life Reduction in Case 3

Table 4. Regression Coefficients in Case 3

ESAL	Selected Road	Parameter a	Parameter b	Parameter c
Extreme	US180L	9.599	0.6074	-3.581
High	US87L	5.043	0.7781	-3.581
Medium	US62L	3.6671	0.8390	-3.581
Low	US377L	2.422	0.9694	-6.206

Next, the regression road life reduction curves were regressed for the selected roads, as illustrated in Figure 35. The regression coefficients are summarized in Table 4.

ANALYSIS

In this section, results from the three previous case studies are analyzed in detail. The interesting findings are addressed as follows.

1. CASE 1

For the High OW/OS traffic scenario, we analyzed the results from Figure 32 and Table1.

In a short-term period (i.e., pavement age is less than two years), the PCS of the selected highways dropped drastically (i.e., in the worst case, the PCS of US 287 reduced from 100 to 85 in less than two years). The reasons are two-fold: the high level of OW/OS loads and none or minimal repair interventions scheduled in the early age of pavement. The reduction speed of pavement performance in the four climate zones (as measured by PCS) shows the following trend:

Zone 1 > Zone 3 > Zone 4> Zone 2

In a long-term period (i.e., pavement age is more than five years), the reduction speed of pavement performance in the four climate zones shows a different trend:

Zone 3 > Zone 4 > Zone 1 > Zone 2

It is reasonable to observe these different trends since we take the prior M&R history as a critical variable in the regression process. Thus, the regression curves reflect the combined effects of pavement aging, OW/OS traffic loads, and M&R interventions.

For the Low OW/OS scenario, we show findings in Figure 33 and Table 2.

In a short-term period (i.e., pavement age is less than four years in this case), the reduction speed of pavement performance (as measured by PCS) shows the following trend:

Zone 4 > Zone 3 > Zone 2 > Zone 1

This trend is consistent with our logical understanding about the climatic effects on pavement: without implementing any M&R interventions at the early age of pavement, pavements in cold and dry weather have a better performance than those in warm and wet weather.

In a long-term period (i.e., pavement age is more than five years in this case), the roads present various trends in pavement performance reduction. This finding is reasonable since M&R actions will be implemented on pavement as time goes by, and our regression models take the prior M&R history as the critical variable. In other words, the observed trends present the combined effects of M&R actions and climatic effects on the pavement's later age behavior.

It should be noted that the performance of roads in this scenario has dropped much more than that of the roads in the first scenario in the whole service life (20 years in this case). This finding is reasonable since we consider the effects of prior M&R activities in our regression models. Normally, the DOTs give more attention to the roads with high OW/OS traffic loads and implement more frequent M&R actions. In this regard, the pavement performance of these roads can be maintained well and their PCS are usually kept at a higher level during the whole service life.

2. CASE 2

From Figure 34 and Table 3, we have some findings about the results.

- In a short-term period (i.e., pavement age is less than four years in this case), the pavement performance drops only due to the level of OW/OS loading. The trend clearly shows that the greater the number of OW/OS vehicles, the more damage to the road. The reduction speed has the following trend:
  - ➢ High OW/OS Loading > Medium OW/OS Loading > Low OW/OS Loading

- In a long-term period (i.e., pavement age is more than four years in this case), the reduction speed presents an opposite trend:
  - ➢ High OW/OS Loading < Medium OW/OS Loading < Low OW/OS Loading

This finding is reasonable since we consider the prior M&R history as the key factor in our regression model. It is obvious that the roads that transport high volumes of OW/OS vehicles are usually implemented with more frequent M&R actions than the ones with low OW/OS loading.

3. CASE 3

The regression curves in Figure 35 present a clear trend of the pavement service life reduction under various levels of OW/OS loading:

ΔLife(%) (Extreme) > ΔLife(%) (High) > ΔLife(%) (Medium) > ΔLife(%) (Low)

The observed trend is consistent with our logical expectation: the greater the number of OW/OS loads, the more pavement damage, and hence the more reduction of pavement service life. More specifically, in this case, when the accumulative ESAL is 10 million, the service life reduction is 35%, 26%, 22%, and 18% for the roads with extreme, high, medium and low OW/OS loads, respectively.

DISCUSSION

Routing and permitting of oversize and overweight vehicles is a significant issue that needs to be addressed not only in Texas but across the states, as most OW/OS loads travel multiple states before reaching their destination. During the two-year research period, the researchers met some technical challenges and problems:

1. The PMIS datasets from TxDOT are limited to some extents so that not all the information about roads in every class was available.
2. The two GIS-based and Web-based routing systems are based on the third-party software (i.e., Mapsuite and ArcGIS WebApp Builder) instead of open source software. Sometimes it is difficult to achieve some functions due to the restrictions of third-party software.
3. A method to find usable data from a large number of data effectively and efficiently was an issue for the researchers.

Recommended future improvements to the routing tool include:

- Develop a more user-friendly interface for the tool
- Continue improving the functions for the tool such as geo-analysis
- Develop a more precise and comprehensive regression function for the pavement performance models with consideration of more related factors such as repair and maintenance cost
- Continue to find the relationship between OW/OS vehicles, road lifespan, and road maintenance and rehabilitation from PMIS data
- Satisfy the requirements of specific users and broaden the tool's practical application value

CONCLUSIONS

In this project, we presented the work of developing two GIS routing assistance tools to optimize the OW/OS routes based on the historical and expected heavy traffic level and pavement condition. Focus was on:

(1) developing a desktop-based routing assistance tool;

(2) developing a web-based routing assistance tool; and

(3) evaluating the impact of OW/OS loads to highway pavements by analyzing historical data.

For developing the GIS routing assistance tools, we achieved objectives based on Mapsuite and ArcGIS WebApp Builder software for the desktop-version and web-version, respectively. Some functions are ready to use, while some specific custom requirements need to be re-developed. The user-friendly interface of the routing system is easy for both administrators and drivers to use.

For evaluating the impact of OW/OS loads to highway pavement, first, we consolidated the data from a database and previous projects. Second, we developed a pavement performance model with consideration of multiple factors. Last, we designed three case studies to evaluate highway pavement performance in different OW/OS scenarios and combinations of the related factors.

The product of this project will provide guidance on the criteria to design and maintain highway structure and pavement. The pavement performance models have laid a basis for other similar projects, i.e., developing an optimal routing algorithm to significantly reduce road damage from OW/OS vehicles. In addition, the web-based routing system provides valuable lessons for other states that are looking for such a website to solve OW/OS vehicles routing issues.

IMPLEMENTATIONS / TECHNOLOGY TRANFER

The products and reports from this study will provide TxDOT and the MCD department with a useful tool to visualize and optimize the routing process. It will also provide guidance on the parameters and criteria needed to design highway alignments and design and maintain highway structure and pavements.

The following products/reports are prepared as part of this project:

- Electronic *Origin-Destination Matrix* and the *Digital Route Map* with combined pavement and routing information
- Final Research Report documenting the findings from this research and guidance for operation of the routing system.

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1.   APPENDIX A

Attached CD-ROM is the installation file for desktop-version GIS routing assistance tool.

2. APPENDIX B

As of the date of this report, the website link for the Web-version GIS routing tool is: https://myweb.ttu.edu/dawu/