Calculating Road User, Crash Mitigation and Local Business Impact Costs Generated by Pavement Rehabilitation, Maintenance and Other Roadway Reconstruction Projects

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List of Acronyms

AADT……Annual Average Daily Traffic
AASHTO……American Association of State Highway Transportation Officials
AC……Asphalt Concrete
ADT……Average Daily Traffic
ALDOT……Alabama Department of Transportation
AMDT……Average Monthly Daily Traffic
BLS……Bureau of Labor Statistics
CMC……Crash Mitigation Cost
CO……Carbon Monoxide
CPI……Consumer Price Index
CTPP……Census Transportation Planning Products
CU……Combination Unit Freight
DOT……Department of Transportation
EC……Emission Cost
EMFAC……California Emission Factors Model
EPA……Environmental Protection Agency
FHWA……Federal Highway Administration
GDOT……Georgia Department of Transportation
HERS-ST……Highway Requirements System - State Version
HSIS……Highway Safety Information System
HSM……Highway Safety Manual
IRB……Institutional Research Board
KABCO……FHWA's Crash Severity Scale
LBIC……Local Business Impact Cost
LTC……Lost Time Cost
NOx……Nitrogen Oxides
OC……Operating Cost
PCC……Portland Cement Concrete
PDO……Property Damage Only
PENNDOT……Pennsylvania Department of Transportation
PM2.5……Particulate Matter
PRPC……Pavement Rehabilitation Project Cost Tool
RUC……Road User Cost
SU……Single Unit Freight
TTI……Texas A&M Transportation Institute
VMT……Vehicle Miles Traveled
VOC……Volatile Organic Compounds
VoT……Value of Time

1. Introduction

Roadway maintenance and rehabilitation is a critical and ubiquitous activity for state, county, and city engineers across the country. With this task, engineers constantly identify effective and efficient scheduling and rehabilitation methods that offer the lowest impact on local users and businesses. Asphalt concrete (AC) rehabilitation projects have the advantage of a fast turnaround project timeline which could reduce immediate residual economic costs to the surrounding area. These blanketing costs need to be considered in the pavement type selection process and construction scheduling which this report will attempt to cover.

Past research regarding lifecycle cost analyses tends to focus a limited scope on construction-related costs (*1, 2*), while other sources and studies are currently out-of-date or over simplified (*3, 4, 5, 6*). There are many factors affecting Road User Costs (RUCs), crash mitigation costs, and local business impact costs that need to be simultaneously accounted for in order to accurately calculate construction related cost values. Most importantly, no relevant data-driven work exists to quantify local business impacts of work zones beyond broad discussions about including local business owners in project planning (*5, 6, 7*).

Therefore, the objective of this report is to update the white paper *Estimating User Costs of Asphalt and Concrete Pavement Rehabilitation* (*8*) by developing a comprehensive set of data-driven, nationally transferrable metrics that quantify the costs associated with asphalt and concrete pavement rehabilitation in terms of (a) road user costs, (b) crash mitigation costs, and (c) local business impact costs. Additionally, how these costs vary by (a) types of pavement rehabilitation, (b) surrounding development (urban vs rural), and (c) types of scheduling alternatives will be addressed. Results are compiled into a convenient Excel tool for users to input project variables and receive associated direct and indirect costs. This tool is intended for any engineer or project manager who needs a streamlined, general analysis of likely impact costs when planning for road rehabilitation scenarios requiring lane closers. Users can test different scheduling alternatives to determine the least impactful course of action. Engineers and project managers can implement the models and tool developed in the project to a) characterize the road user, crash mitigation, and local business impacts of an existing project or projects that are being let for bid; b) to evaluate possible innovative scheduling opportunities in the project planning stage; and c) to illustrate to local business owners the potential loss in revenue they could receive during construction.

This report is organized into sections addressing each associated cost and the impact with the Excel tool. First, a literature review of current methodologies and past research expenditures were collected and addressed. Second, updated road user costs was compiled from several reputable sources and studies with a general example presented to guide the reader through the process. Third, crash mitigation cost results were covered from research conducted across an eight state data set regarding work zone crashes. Next, the methodology and results of the local business impact costs survey and model is addressed. A detailed, step-by-step user guide of the Excel tool is then presented with a subsequent real-world example given. Finally, conclusions from the project are shared.

2. Background Information

Research regarding Road User Costs (RUCs) is a hot topic with years of research dedicated to the subject and multiple federally funded projects commissioned to validate claims. The two main sources for standard RUC values and methodology come from the Federal Highway Administration (FHWA) and the American Association of State Highway Transportation Officials (AASHTO) guides *Work Zone Road User Costs: Conceptions and Applications* and *User and Non-User Benefit Analysis for Highways*, respectively (*6, 9*). In terms of work zone analysis, the FHWA methodology solely focuses on this topic offering a comprehensive guide for determining these costs as well as alternatives to some calculations—such as emissions-based on individual state specific research. However, most of the provided values are out-of-date by several years, or in some cases decades, which in turn can greatly underestimate the actual RUCs. AASHTO's methodology, while just as comprehensive, focuses mainly on RUC improvements from before and after a project is implemented which does in turn require some interpretation to convert to work zone related costs. As with the FHWA's methodology, the provided values are out-of-date by similar timeframes but alternatives are not provided to update easily. Additionally, this methodology assumes the user has several inputs on hand such as average delay times and average hourly traffic; values that traditionally need to be gathered in the field for the best accuracy. Since RUCs are most useful when calculated before a project's implementation, these values need to be calculated off available information using methodology not directly sourced in AASHTO's approach.

Research completed by the Texas A&M Transportation Institute (TTI) on RUCs mimics the simplified methods found in the aforementioned FHWA and AASHTO methodologies, and neither is designed to be transferrable outside of Texas (*10, 11*). While the two RUC reports were published 10 years apart, they both rely on data pulled from the MicroBENCOST software, which provides an overly simplistic analysis of RUCs and lacks vehicle emissions costs. The 2009 report further focuses on referencing outside data sources and industry software methods. For other reviewed publications, the focus tended to ignore costs outside of construction and the resulting operational life cycle costs (*3, 4*).

When focusing on crash mitigation costs, FHWA's RUC publications provided a comprehensive analysis on crash rate calculations and their costs. However, the FHWA concludes by suggesting agencies assign their own crash modification factors since results vary from region to region as well as between published studies (*6*). AASHTO's methodology also provides a section on crash mitigation, but focuses mainly on crash frequency and individual costs as opposed to their contributing factors (*9*). After further evaluation, several methods for determining work zone crash factors were identified from publications. Both Duncan's and Kockelman's successes with the ordered probit model in identifying crash injury thresholds proved to be promising in determining a viable predictive model (*12, 13*). Their methodology, which ultimately was chosen for this study, not only allowed the identification of statistically significant crash severity characteristics, but the ability to predict, given several road and driver characteristics, the probable crash severity to occur. Similarly, Li in his study used a simplified logistic regression model to determine the statistically significant crash severity characteristics of Kansas crashes (*14*). The shortfall of Li's method is the lack of a resulting threshold calculation so the user is left with identified crash factors but no way to probabilistically predict a possible crash scenario. Regarding actual work zone crash mitigation techniques, Meng found in a study of long-term work zones that a 20 percent reduction in the speed limit resulted in a 62 percent decrease in fatality risk (*15*). In that same vein, it was found that reducing the work zone speed was more effective than reducing the emergency response time. When construction workers were surveyed in Debnath's Australian study, they identified wet weather, speeding, and nighttime conditions as perceived hazards to their and passing drivers' safety (*16*). As this report's model is analyzed, it would expect these factors play heavily in crash severity determination to validate these hypotheses.

Regarding local business impact costs, very little prior research has be done, and from what can be determined, not a single study has be conducted on a national scale. For the existing reports, the FHWA's RUC methodology offers references to previous studies, discussed below, but takes a qualitative rather than quantitative approach to the subject; while AASHTO only discusses the possible long-term benefits of improvement projects to the local economy. The first report FHWA refers to is a series of TTI studies completed in the late 90s on road-widening projects. Wildenthal's and Buffington's surveyed affected business owners on their thoughts and experiences during construction and compared their answers to field data (*17, 18*). Data from the abutting businesses' gross sales showed a 5 percent decrease during construction which was not nearly as negative as business owners originally perceived. However, these abutting businesses received higher traffic from construction workers so net loss from regular customers could not be fully calculated.

The other recommended report from the FHWA referred to a multiyear study for the town of Dubois, Wyoming, during a major highway improvement project (*19*). This report completed a more comprehensive analysis, compared to the previous references, documenting before and after conditions as well as different mitigation technique impacts. Overall, data was gathered from businesses, traveler surveys, traffic counts, and general economic sources. This study found that while traffic volumes decreased during construction, the majority of surveyed local businesses stated they saw no change in gross sales, the number of customers, or net profit. Wyoming Department of Revenue data backed this claim showing the health of individual businesses was "very positive" once all individual businesses were equally weighted. Additionally, of the mitigation techniques employed to limit loss of business, an active public marketing campaign proved to be the most effective.

When the section of Interstate 5 running through Sacramento, California was subject to "The Fix" improvement project, Ye and his group conducted a study on commuter responses through a series of surveys and field data counts (*20*). Their non-work activity results found 44 percent of those surveyed changed their regular routes to avoid delays and construction. Additionally, more than 20 percent changed either the location or time of their activity, with 18 percent changing the day of the activity, and an additional +20 percent choosing to cancel the activity all together.

Overall, this past research directed the tool development in three main ways. First, road user costs must be comprehensive and should incorporate the widely accepted FHWA and AASHTO Road User Cost Methodologies. Second, ordered probit models are a reliable way to estimate (and predict) crash severity based on significant road, environment, and driver characteristics. Third, understanding individuals' travel behavior in response to work zone congestion. While no one has studied this in the past, this study must incorporate nationally representative trends, different shopping types, and different work zone characteristics.

3. Road User Costs

3.1 Background

Road User Costs (RUCs) are the first of the three impact categories associated with roadway pavement rehabilitation work and quantified in this report. RUCs are defined as the total monetary and temporal costs experienced by both personal and freight vehicle road users when faced with delays caused by lane or total road closures due to rehabilitation work. While RUCs have previously been calculated under a variety of scenarios and for different population groups (2, 5, 7), this section provides a straightforward methodology for calculating RUCs for pavement rehabilitation work synthesized from these past best practices. Specifically, this section calculates the Road User Cost in Total Dollar ($) per Day for any given work zone based on a) lost time costs, b) operating costs and c) emission costs. Additionally, this section provides information on how scheduling rehabilitation work can impact costs.

3.2 Road User Costs Model Explanation

Road User Costs (RUC) for each vehicle *i* in a work zone are most often described using the following equation:

$$RUC_i = LTC_i + OC_i + EC_i$$

Where:

RUC_i = Road User Costs for vehicle *i*

LTC_i = Lost Time Cost for vehicle *i*

OC_i = Operating Cost for vehicle *i*

EC_i = Emissions Cost for vehicle *i*

Each component is calculated in dollars per vehicle and outlined in detail in the following sections. These RUCs can be calculated for each individual vehicle and summed for the entire volume of traffic that passes through the work zone. However to streamline the process, instead of calculating for each vehicle, RUCs will be calculated for each vehicle class *c* instead. For the purpose of this report, three vehicle classes are specified: personal, single-unit freight, and combination freight. It is important that RUCs for work zones be focused on impacts generated from the work zone beyond those experienced by motorists during normal traffic operations when the work zone is not present.

Impacts of Scheduling Rehabilitation Work on Costs

One of the simplest ways to minimize RUCs is to reduce the number of vehicles affected by the work zone. This can be achieved by scheduling projects during off-peak driving times. First, project managers can select a month or day of the week that minimizes the traffic volumes (as seen in Tables 1 and 2 (12)). These tables present the Average Daily Traffic (ADT) Factors for given months (Table 1) and days of the week (Table 2) for different roadway classifications in Georgia, as an example. To convert from Annual Average Daily Traffic (AADT) to Average Monthly Daily Traffic (AMDT) or Average Daily Traffic (ADT), respectively, simply divide the AADT by the appropriate factor. AADT can be found readily from most state or city DOT websites and other relevant sources. As for interpreting Tables 1 and 2 below, the higher the factor value, the smaller the estimated AMDT or ADT. Table 1 highlights that AMDT is greatest during the summer and fall months, so paving projects completed in winter months will have lower overall RUCs when based solely on vehicle volume impacts. It is important to note that these volumes represent a location in which warmer winter months allows for more paving, but this is not necessarily an option in areas with colder winter climates. Similarly, Table 2 highlights that ADT is greatest during the weekdays with the greatest volumes occurring on Fridays and the lower volumes occurring on the weekend. The differences in urban and rural locations are more evident in Table 1 than in Table 2.

Table 1: GDOT AMDT Factors (12)

Road Classification	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rural/Small Urban Interstate	**1.18**	**1.08**	**0.97**	**0.95**	**1.01**	**0.95**	**0.91**	**0.94**	**1.06**	**1.04**	**1.00**	**0.96**
Rural Arterial	**1.14**	**1.08**	**1.02**	**0.98**	**0.97**	**0.96**	**0.97**	**0.98**	**0.98**	**0.94**	**0.97**	**1.04**
Rural Collector	**1.20**	**1.05**	**1.00**	**0.95**	**0.95**	**0.98**	**0.97**	**0.95**	**0.98**	**0.94**	**1.03**	**1.05**
Urbanized Interstate	**1.11**	**1.05**	**0.99**	**0.99**	**0.99**	**0.94**	**0.97**	**0.95**	**1.01**	**1.00**	**1.01**	**1.03**
Urbanized Arterial	**1.06**	**1.01**	**0.99**	**1.01**	**0.96**	**0.99**	**1.02**	**1.00**	**0.99**	**0.96**	**1.00**	**1.03**
Urbanized Collector	**1.05**	**0.99**	**0.95**	**0.95**	**0.96**	**1.00**	**1.01**	**1.04**	**1.03**	**0.92**	**1.06**	**1.08**

Table 2: GDOT ADT Factors (12)

Road Classification	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
Rural/Small Urban Interstate	**0.99**	**1.07**	**1.12**	**1.08**	**1.02**	**0.85**	**0.93**
Rural Arterial	**1.29**	**0.99**	**0.99**	**0.98**	**0.95**	**0.85**	**1.04**
Rural Collector	**1.14**	**1.04**	**1.05**	**1.04**	**1.01**	**0.87**	**0.99**
Urbanized Interstate	**1.39**	**0.98**	**0.94**	**0.92**	**0.91**	**0.86**	**1.18**
Urbanized Arterial	**1.55**	**0.94**	**0.92**	**0.92**	**0.92**	**0.84**	**1.17**
Urbanized Collector	**1.57**	**0.95**	**0.94**	**0.93**	**0.88**	**0.84**	**1.18**

Finally, in Table 3, from FHWA (11), shows the distribution of traffic in urban and rural areas throughout a typical weekday. To interpret Table 3 below, the lower the ADT percentage, the lower the traffic volume. Again, if a project manager seeks to minimize RUCs, it would be preferred to schedule active work zones during the early morning hours in both urban and rural situations to avoid active work zones operating during 0600 to 2059.

Table 3: Distribution of Daily Traffic by Time Interval

Time Interval	Urban (% of ADT)	Rural (% of ADT)
0000 – 0259	**2.7**	**4.6**
0300 – 0559	**2.9**	**4.6**
0600 – 0859	**19.2**	**10.2**
0900 – 1159	**15.2**	**16.0**
1200 – 1459	**17.2**	**18.9**
1500 – 1759	**22.9**	**23.6**
1800 – 2059	**13.1**	**14.0**
2100 – 2359	**6.8**	**8.1**

3.3 Road User Costs Model Components

Our RUC Model quantifies three avenues in which personal and freight vehicles are affected by delays in work zones: lost time costs, operating costs, and emission costs. Each component is outlined below.

Lost Time Costs

The first component of RUCs are costs due to personal and business time lost when travelers are delayed reaching their ultimate destination. The Lost Time Cost *(LTC)* for each vehicle class *c* that travels through a work zone (in dollars per vehicle) is calculated as:

$$LTC_c = n_c \times VoT_c \times O_c \times D$$

Where:

LTC_c = Lost Time Cost for vehicle class *c* (in dollars per vehicle)

n_c = Number of vehicles of vehicle class *c*

VoT_c = Value of Time for vehicle class *c* (in dollars per hour)

O_c = Vehicle Occupancy of vehicle class *c* (in persons per vehicle)

D = Average Delay of the work zone (in hours)

Values for these components are outlined below.

When calculating Total LTC for the work zone for the day, one will need to sum the individual LTC values for each vehicle type. As there are three vehicle classes outlined in this report (personal, single-unit freight, and combination freight), the calculation is generalized by multiplying the LTC value for each vehicle/purpose type with the number of vehicles that fall in that category and adding these sums.

Value of Time (VoT). It is well documented that individual and freight vehicles experience different values of travel time (and therefore face different values of lost time due to delay). Table 4, based on values from AASHTO and FHWA (6, 9, 10), provides guidance on a range of values of travel time for passenger and freight vehicles under different trip purposes.

Table 4: Personal and Freight Values of Travel Time

Travel Purpose	Value of Time	
	PERSONAL VEHICLES	**FREIGHT VEHICLES**
General Personal (Local)	**$12.91**	**--**
General Personal (Intercity)	**$18.07**	
General Work/Business	**$30.97**	**$30.46**
Transport & Warehousing		**$28.10**
Utilities		**$46.39**

Vehicle Occupancy (O). Vehicle occupancy can also vary by vehicle type and region. While states and metropolitan planning organizations are likely to have information specific to their region, Table 5 provides average vehicle occupancy for the different regions of the US if local information is unavailable. These rates are taken from Census Transportation Planning Products (CTPP) estimates of the American Community Survey 2006 – 2010 (*21*). Refer to Appendix A for an outline of states in a region.

Table 5: Average Vehicle Occupancy by Census Region

Census Region	Average Vehicle Occupancy	
	PERSONAL VEHICLES	**FREIGHT VEHICLES**
U.S. Overall	**1.07**	**1.00**
Northeast	**1.06**	**1.00**
Midwest	**1.06**	**1.00**
South	**1.14**	**1.00**
West	**1.08**	**1.00**

Average Delay (D). The average delay used in the LTC equation is identified from the work zone analyzed. This value can be measured by tracking vehicles through the work zone. It is important to recognize that this delay (in hours) measures the additional delay experienced by vehicles beyond the typical delay one would experience on the roadway without the work zone present.

Operating Costs

The second component of RUCs are additional costs related to idling a vehicle during a work zone traffic delay, referred to as vehicle operating costs. Personal and freight vehicles incur typical operating costs every mile they travel, but when a work zone generates a detour or congestion, vehicles generate additional operating costs. According to AASHTO, these operating costs include fuel, maintenance, insurance, and registration costs of the vehicle; directly perceived out-of-pocket expenses *(9)*. For work zone applications, current practice emphasizes the use of fuel costs.

Operating costs are calculated differently for personal and freight vehicles. The Operating Cost (OC) for the **personal vehicle class** traveling through a work zone (in dollars per vehicle) is calculated as:

$$OC_{personal} = FC_{personal} \times D \times FP + OwnC_{personal} \times L$$

Where:

$OC_{personal}$ = *Operating Costs for personal vehicles (dollars per vehicle)*

$FC_{personal}$ = *Fuel Consumption for personal vehicles (in gallons per hour)*

FP = *Fuel Price (in dollars per gallon)*

D = *Average Delay in the work zone (in hours)*

$OwnC$ = *Ownership Cost of the vehicle (in dollars per mile)*

L = *Length of the work zone (in miles)*

Values for these components are outlined below.

Additionally, FHWA (12) recommends the Operating Cost RUC (OC) for each **freight vehicle *i*** that travels through a work zone (in dollars per vehicle) follow the same function as above with an additional inventory cost based on delay:

$$OC_i = \begin{cases} FC_i \times D \times FP + 0.20 \times D & for\ Single\ Unit; 25{,}000lb\ vehicles \\ FC_i \times D \times FP + 0.34 \times D & for\ Combination; 42{,}000lb\ vehicles \end{cases}$$

FHWA suggests hourly inventory costs of $0.20/hr for single-unit trucks (25,000 lb) and $0.34/hr for combination trucks (42,000 lb) when adjusted from 2010 dollars.

When calculating Total OC for the work zone for the day, one will need to sum the individual OC values for each vehicle type. As there are only 3 vehicle types (personal, single unit freight at 25,000 pounds, and combination freight at 42,000 pounds) used in the calculation, one can simplify the calculation by multiplying the OC value for each vehicle type with the number of vehicles that fall in that category and adding these three categories together.

Fuel Consumption (FC). AASHTO evaluated a variety of vehicle fuel consumption rates (in gallons per hour) (9), and these are averaged in Table 6 for application in this report. AASHTO's calculations account for the full range of vehicles in the current US fleet, and assume vehicles are owned, on average, for 75,000 miles.

Table 6: Fuel Consumption by Vehicle Type (Gallons per Hour)

Traffic Speed	Personal Vehicle (Gasoline Only)	Freight (Diesel Only)	
		SINGLE UNIT	**COMBINATION**
25	**1.56**	**5.82**	**14.52**
35	**2.04**	**8.94**	**19.62**
45	**2.58**	**12.36**	**24.66**
55	**3.24**	**15.96**	**29.70**
65	**3.96**	**19.68**	**34.68**

Fuel Price (FP). Fuel prices vary greatly and change frequently. For up-to date estimates, users should refer to the US Energy Administration for current fuel prices across different US regions.

Ownership Cost (OwnC). For every mile traveled, a vehicle will lose value and incur wear and tear. OwnC factor summarizes these effects across a variety of vehicle types. AASHTO (9) provides a complete review of automobile operating ownership costs across small cars, midsize cars, large cars, SUVs and vans, as seen in Table 7. For this report, personal vehicle ownership costs are simplified to an average of $0.21 per mile.

Table 7: National Average Vehicle Ownership Costs (dollars per mile)

SMALL CAR	MIDSIZE CAR	LARGE CAR	SUV	VAN
$ 0.16	**$ 0.196**	**$ 0.219**	**$ 0.253**	**$ 0.219**

Average Delay (D). The average delay used in the Operating Cost equation is identified from the work zone being analyzed. This value can be measured by tracking vehicles through the work zone. It is important to recognize that this delay measures (in hours) the additional delay experienced by vehicles beyond the typical travel time one experiences on the roadway without the work zone present.

Length of Work Zone (L). This is the length of the work zone in miles.

Emissions Costs

The third component of RUCs are incurred on the environment through air pollutants, such as carbon monoxide (CO) and particulate matter (PM2.5), as well as greenhouse gas emissions which include direct emissions that are not recognized as air pollutants but do contribute to global climate change (6). The Emission RUC *(EC)* for each vehicle class *c* that travels through a work zone (in dollars per vehicle) is calculated as:

$$EC_c = \sum^{P} ER_{pc} \times EC_{pc} \times L \times 0.00000110231$$

Where:

EC_c= Emission RUC for each vehicle class *c* (dollars per vehicle)

ER_{pc} = Emission Rate of pollutant p for vehicle class *c* (in grams per mile)

EC_{pc} = Emission Cost of pollutant p for vehicle class *c* (in dollars per ton)

L = Length of the work zone (in miles)

The additional factor is a conversion between grams and tons. Values for these components are outlined below.

Emission Rate (ER). The values presented below, in grams per mile are the 2017 aggregated estimates used by the California Emission Factors (EMFAC) model. Emissions included are CO, PM2.5, EPA-defined Volatile Organic Compounds (VOC) and Nitrogen Oxides (NOx). These values represent he average California emission rates across all tested model years with the "personal vehicle" category containing all passenger car models and the "freight" category describing all medium-heavy and heavy-heavy diesel trucks. Additionally, these values reflect running emissions and assume vehicles are moving through the work zone.

Table 8: California Emission Rates for Personal and Freight Vehicles from EMFAC Model (g/mile)

Traffic Speed	Personal Vehicle (Gasoline Only)				Freight (Diesel Only)			
	CO	VOC	NOX	PM2.5	CO	VOC	NOX	PM2.5
5	**1.987**	**0.151**	**0.175**	**0.011**	**5.096**	**1.679**	**16.898**	**0.191**
15	**1.488**	**0.062**	**0.123**	**0.005**	**2.396**	**0.781**	**9.761**	**0.124**
25	**1.189**	**0.033**	**0.099**	**0.002**	**1.212**	**0.325**	**5.89**	**0.077**
35	**1.007**	**0.022**	**0.088**	**0.002**	**0.773**	**0.199**	**4.713**	**0.066**
45	**0.897**	**0.018**	**0.086**	**0.001**	**0.513**	**0.13**	**4.077**	**0.066**
55	**0.819**	**0.019**	**0.089**	**0.001**	**0.398**	**0.102**	**3.791**	**0.079**
65	**0.738**	**0.022**	**0.095**	**0.001**	**0.374**	**0.095**	**3.607**	**0.082**

Emission Cost (EC). The general monetary costs for each emission type, pulled for the Highway Economic Requirements System – State Version (HERS-ST) software, can be found below in Table 9. These costs are adjusted from the year 2000 estimates using the BLS CPI Calculator and rounded to the nearest $50 increment, and they describe the economic costs of health impacts causes by emissions. The CPI values incorporate both actual and perceived health costs for average consumers (12).

Table 9: Adjusted HERS-ST Emissions Costs by Surrounding Development ($/mile)

Development	Personal Vehicle (Gasoline Only)			
	CO	VOC	NOX	PM2.5
Urban	**$150**	**$5850**	**$7650**	**$6800**
Rural	**$75**	**$3900**	**$5100**	**$3400**

For this report, the emissions cost equation can be simplified as:

$$EC_c = EF_c \times L$$

Emission Factor (EF). The values from the previous two tables are combined into Table 10. This table simplifies the EC calculation based solely on the vehicle type and location of the work zone.

Table 10: Summarized Emissions Costs per Mile

Traffic Speed	Personal Vehicle (Gasoline Only)		Freight (Diesel Only)	
	URBAN	RURAL	URBAN	RURAL
5	**$0.0028604**	**$0.0018385**	**$0.1555966**	**$0.1033520**
15	**$0.0017205**	**$0.0010998**	**$0.0886732**	**$0.0588945**
25	**$0.0012592**	**$0.0008042**	**$0.0525418**	**$0.0348983**

35	**\$0.0010654**	**\$0.0006800**	**\$0.0416490**	**\$0.0276622**
45	**\$0.0009971**	**\$0.0006388**	**\$0.0357978**	**\$0.0237686**
55	**\$0.0010159**	**\$0.0006535**	**\$0.0332840**	**\$0.0220797**
65	**\$0.0010725**	**\$0.0006934**	**\$0.0317057**	**\$0.0210244**

These costs are based on the difference in emission levels for traffic between when the work zone is present prior to the work being started. This is characterized as:

$$\Delta EC_c = EC_{c,work\ zone} - EC_{c,pre-construction}$$

Where:

ΔEC_c = Change in emissions cost during construction for vehicle class *c* (dollars)

$EC_{c,work\ zone}$ = Emissions Cost for vehicle class *c* based on work zone observed speed

$EC_{c,pre-construction}$ = Emissions Cost for vehicle class *c* based on pre-construction observed speed

Each separate EC value would be solved as outlined above with the only difference being the traffic speed. For example, if an urban roadway was to be subjected to a work zone calling for a drop in the posted speed limit from 55mph to 35mph, the $EC_{c,pre-construction}$ variable would refer to the “Traffic Speed: 55” row of Table 10 while the $EC_{c,\ work\ zone}$ variable would refer to the “Traffic Speed: 35” row. In most cases, when the speed decreases, this will result in a negative emissions cost, highlighting the fact that slower speeds are reducing vehicle emissions.

4. Crash Mitigation Costs

4.1 Background

Crash Mitigation Costs (CMCs) are the second of the three category impacts associated with roadway pavement rehabilitation work and quantified in this report. CMCs are defined as the cost associated with the most likely crash type to occur at a work zone. Crashes and costs are evaluated using the FHWA's KABCO scale (outlined below in Table 11). This scale designates 5 types of crashes that can occur within a work zone, on a severity scale from property damage only (PDO) to fatal crash (K). Additionally, the typical cost associated with each crash type, including both direct and indirect costs, is reported in the Highway Safety Manual (6).

Table 11: Comprehensive Unit Costs by FHWA Severity Scale (6)

CRASH SEVERITY CODE	DESCRIPTOR	COST PER INJURY ($)
K	**FATAL**	**4,008,900**
A	**INCAPACITATING INJURY**	**216,000**
B	**NON-INCAPACITATING INJURY**	**79,000**
C	**POSSIBLE INJURY**	**44,900**
PDO	**PROPERTY DAMAGE ONLY**	**7,400**

This section calculates a Total Dollar ($) per Project Duration Crash Mitigation Cost for any given work zone based on the most likely crash to occur at the specified location. Based on national work zone crash statistics, if a work zone experiences a crash, it is most likely that the work zone will not encounter more than one crash. The methodology for identifying the most likely crash for a given work zone is outlined below.

4.2 Data Collection

The work zone crash type prediction model is based on representative work zone crash records. The data includes crashes from eight states (Alabama, California, Illinois, Maine, North Carolina, Ohio, Pennsylvania, and Washington) across the country, in order to ensure that the model is transferrable for work zones in any US region. Specifically, crash data was collected from three primary sources: a) the Highway Safety Information System (HSIS), b) the Alabama Department of Transportation work zone crash database compiled by Auburn University, and c) the PENNDOT OpenData Portal. Crash records were collected from 2008 to the most recent year, which varied by state from 2010 to 2015. The database across all states and years includes 4,324,686 total crashes and 89,212 work zone related crashes. The specific number of work zone crashes from each state across each year are presented in Table 12. It is important to recognize that the crash records used in this analysis are generated by a law enforcement officer, who designates the location (i.e. in a work zone or not) of the crash and recorded the vital information.

Table 12: Work Zone Crashes Collected Across the United States by Year

STATE	2008	2009	2010	2011	2012	2013	2014	2015
ALABAMA	591	1,429	871	905	604	403	94	-
CALIFORNIA	157,687	150,782	154,438	150,465	145,776	-	-	-
ILLINOIS	208,357	144,191	144,512	-	-	-	-	-
MAINE	30,385	28,199	27,356	-	-	-	-	-
NORTH CAROLINA	146,515	148,194	160,739	157,919	158,747	165,646	-	-
OHIO	128,625	137,205	123,792	140,776	127,739	130,157	-	-
PENNSYLVANIA	126,170	121,788	121,609	125,602	124,489	124,350	121,533	127,354
WASHINGTON	44,252	42,450	42,460	42,700	43,637	43,469	-	-
TOTALS	842,582	774,238	775,777	618,367	600,992	464,025	121,533	127,354

Each crash includes many variables in addition to crash severity, including driver characteristics, crash characteristics, roadway characteristics, and project characteristics. Due to the range of data sources, all record variables were normalized. Specifically, every record was restructured to match the North Carolina data dictionary, as it provided the most flexibility in variable definitions. A few states identified multiple at-fault persons in multiple-vehicle crash, so the ages and genders for all the people at-fault in these crashes were combined in the record. This resulted in some crashes having several different age and gender categories when ran through the final model. Additionally, a few variables were either not present in each state's dataset or were not included in the responding officer's report. If this occurred, the variable was recorded as "other" or "unknown", as appropriate. Finally, any crashes showing an unknown KABCO variable were removed from the dataset to limit error in the final statistical model.

4.3 Crash Mitigation Costs Model Estimation

The most likely crash type in a given work zone is calculated using an ordered probit regression model. This section introduces the model structure and estimation results.

Ordered Probit Regression Model

The ordered probit regression model is the most appropriate method for predicting crash type because this dependent variable is a) categorical, meaning that crashes can only be labeled as one type, and b) presented in an ordered scale, meaning that the crash types move from low severity to high severity.

The ordered probit regression model is similar to a continuous linear regression model, in that it first calculates a continuous underlying unitless "likely crash severity" score for each work zone based on the input independent variables. This score has no upper or lower limits, but a higher score translates to a higher likelihood of a severe crash. This "likely crash severity" score equation can be written as:

$$y^* = \beta' x + \epsilon$$

Where:

y^* = Injury severity level

β = Matrix of estimated coefficients

x = Matrix of independent variables

ε = Error term (assumed to be normally distributed)

Independent variables describe driver characteristics, crash characteristics, roadway characteristics, and project characteristics. These are all categorical, indicator variables (for ease in application) with the exception of AADT and posted speed limit. The coefficients provide relative weights for each independent variable, assuming all other variables are held constant.

Next, the crash type categories are mapped to this underlying "likely crash severity" scale as demonstrated in Figure 1. One can see that the continuous "likely crash severity" score is partitioned into the scaled crash types, such that if a work zone receives a score between γ_3 and γ_4, the most likely crash type result is an "Incapacitating Injury". The thresholds between crash types are estimated specific for the model and do not need to be evenly spaced, highlighting the varying ranges of severity the can occur within each crash type.

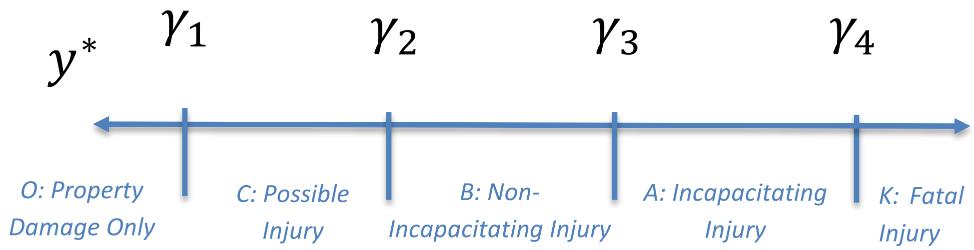


Figure 1: Likely Crash Severity Scale

This mapping can also be written as:

$$y = \begin{cases} K & if\ y^* > \gamma_4 \\ A & if \gamma_3 \le y^* < \gamma_4 \\ B & if \gamma_2 \le y^* < \gamma_3 \\ C & if \gamma_1 \le y^* < \gamma_2 \\ O & if\ y^* \le \gamma_1 \end{cases}$$

The ordered probit model assumes independence of irrelevant alternatives, low collinearity, and a normal distribution of error terms. This model is commonly used in crash severity analyses to identify factors affecting crashes. For example, Duncan used this method to determine injury severity level factors for heavy truck-passenger car rear-end collisions finding unlit and wet roads greatly increased the probability of a severe injury (*12*). Kockelman found through her research two-vehicle crashes had lower injury severities for their drivers as opposed to their passengers (*13*).

The model coefficients and thresholds were estimated using maximum likelihood estimation. The model was iteratively estimated, removing variables that were insignificant at the 99% confidence level until a final model was derived. The chi-squared likelihood ratio of the final model is 39034.15, which greatly exceeds the critical values at any level of significance.

Estimation Results

The final model estimation results are presented in Table 13.

Table 13:Estimation Results

		IMPACT	
		COEFF.	***P-VALUE***
MODEL CHARACTERISTICS	Injury Thresholds		
	No Injury/Property Damage Only	< 2.739	
	Class C Injury (Possible Injury)	2.739	< 0.001
	Class B Injury (Non-Incapacitating Injury)	3.214	< 0.001
	Class A Injury (Incapacitating Injury)	3.699	< 0.001
	Fatal Injury	4.223	< 0.001
CRASH CHARACTERISTICS	Weather (Base: Other)		
	Clear	-	-
	Cloudy	-	-
	Rain	-0.333	< 0.001
	Snow	-0.548	< 0.001
	Census Region (Base: South)		
	Midwest	0.288	< 0.001
	Northeast	-	-
	West	1.525	< 0.001
	Season (Base: Winter)		
	Spring	-	-
	Summer	-0.048	0.001
	Fall	-0.059	< 0.001
	Time Of Week (Base: Weekend)		
	Weekday	-0.134	< 0.001
	Accident Type (Base: Other)		
	Ran Off Road	0.486	< 0.001
	Struck Object	0.256	< 0.001
	Rear End	0.214	< 0.001
	Sideswipe	0.392	< 0.001
	Angle	0.216	< 0.001
	Driver Age (Base: Unknown)		
	Under 25	-	-
	25 To 34	-	-
	35 To 44	-	-
	45 To 54	-	-

	55 To 64	-	-
	Over 64	-0.057	< 0.001
ROAD CHARACTERISTICS	Rural/Urban Locale		
	Rural	0.240	< 0.001
	Urban	-	-
	Lighting (Base: Other)		
	Daylight	0.318	< 0.001
	Dusk	0.417	< 0.001
	Dawn	-	-
	Dark - Lighted Roadway	0.251	< 0.001
	Dark - Roadway Not Lighted	0.341	< 0.001
	Road Condition (Base: Other/Unknown)		
	Dry	-	-
	Wet	-0.114	< 0.001
	Ice/Snow	-	-
	Roadway Access (Base: Unknown)		
	No Access Control	0.194	< 0.001
	Partial Control	-0.855	< 0.001
	Full Control	-0.631	< 0.001
		-	-
	Roadway Classification (Base: Unknown)		
	Urban Freeways	-0.546	< 0.001
	Urban Freeways Less Than 4 Lanes	-0.733	< 0.001
	Urban 2 Lane Roads	-	-
	Urban Multilane Divided Non-Freeway	-	-
	Urban Multilane Undivided Non-Freeway	-	-
	Rural Freeways	-0.668	< 0.001
	Rural Freeways Less Than 4 Lanes	-	-
	Rural 2 Lane Roads	-0.313	< 0.001
	Rural Multilane Divided Non-Freeway	-	-
	Rural Multilane Undivided Non-Freeway	-	-
	Others	-0.311	0.001
	Lane Width (Base: Unknown)		
	1 To 11 Feet	-0.432	< 0.001
	12 To 20 Feet	-0.503	< 0.001
	21 To 30 Feet	-	-

	Greater Than 30 Feet	-	-
	Surface Composition (Base: Unknown)		
	Asphalt Concrete	-0.188	**<0.001**
	Portland Cement Concrete	-	-
	Other	-0.185	**< 0.001**
	AADT (Continuous)	2.8E-06	**< 0.001**
	Speed Limit (Continuous)	0.051	**< 0.001**
Likelihood Ratio Chi-Square		**39034.15**	
Degrees Of Freedom		**32**	

Although driver gender was found to be statistically insignificant in crash severity, driver age proved to be moderately influential. Drivers over the age of 64 were less likely to have a severe crash when all other factors were held constant. A possible explanation could be the slower speeds drivers of that age would more likely operate. As shown later, slower speeds are less likely to cause higher severity crashes. Previous research showed an opposite impact with an increase in age resulting in a higher chance of injury severity (13). This could be due to methodology differences (continuous versus categorical variable) which would emphasize the larger driver population in the 21 to 55 age range.

Crash time and location played a significant part in determining crash severity. Tested western region states were the most likely states to have a higher severity work zone crash compared to all other census regions when all other factors were held constant. Since data used included California, the state's higher VMT counts could bias the results slightly to reflect the higher number of sever crashes. The Midwest region also showed a penchant for more severe crashes when all other factors were held constant. Once again, this could be due to the bias Ohio data presented with its large number of individual cases. Looking at surrounding locale classification, rural crashes were more likely to be severe than urban crashes when all other factors were held constant. Possible explanations for this could be the higher chances of two-lane, undivided highways that would increase head-on crashes if a lane was closed for rehabilitation.

Weather conditions had somewhat surprising results. Compared to all other unlisted weather events, rain and snow were the least likely to cause a more severe crash compared to the base category, when all other factors were held constant. While it is possible that there is a higher crash rate during these weather conditions, drivers could be operating at lower speeds, which would greatly reduce the severity level of an ensuing crash event. Additionally, because paving operations are limited in adverse weather, there is less opportunity to generate severe crashes. This is once again reflected under the road condition category where wet road conditions were less likely to cause a more severe crash compared to other conditions, when all other factors were held constant.

Regarding seasonality, it played an overall negative role in crash severity with summer and fall being the only statistically significant seasons found compared to winter. From the summary statistics, it was found 64 percent of all work zone crashes occurred during these two seasons, but frequency of road construction occurs during this time at a higher rate than winter and spring seasons resulting in a small bias. Crashes occurring on weekdays (Monday through Friday) were less severe than those on weekends (Saturday and Sunday) when all other factors held constant. As for light conditions, dusk light conditions, compared to all other options, had the highest probability for high severity crashes when all other factors held constant. This could be due to drivers being blinded by the sun; obscuring their vision and increasing crash rates. Unlit highways, compared to all other options, had the second highest probability for high severity crashes when all other factors held constant. Reasons for this are obvious—drivers who can't see the road are more likely to be surprised by work zones. The same can be said for unlit highways where the impact was still high but was statistically safer than unlit roadways. Roadway characteristics and crash type in general greatly influence probable severity outcomes. Higher AADT and posted speed limits resulted in higher likelihoods of a severe crash when all other factors were held constant. Non-access controlled roads were more likely to have severe crashes than all other types, when all other factors were held constant. Possible reasoning could be due to vehicles entering the roadway at random resulting in more right-angle crashes occurring. Full and partial control were less likely to have high severity crashes when all other factors were held constant. This reflects previous research on the subject where controlling access points statistically lowers crash severities and crash frequencies overall (25, 26). Oddly enough, partial control roads were statistically the least likely to increase accident severity. This could be due to access points being situated mainly at controlled intersections but further research would be needed to determine the actual cause. For crash type, crashes that occurred under the "ran of road" and "sideswipe" categories had a higher chance of severity compared to "other" category when all other factors held constant. Similar to comparable previous studies, "rollover" crashes were found to be the deadliest (13); but due to the small sample size (roughly 1 percent) of those types of crashes in the dataset, they were combined into the "other" category in analysis.

Finally, roadway classifications were considered. Both urban and rural freeways were less likely to have high severity crashes than all other categories when all other factors were held constant. This can be attributed to full access control on these roadways, which in turn increases overall safety. Rural two lane roads were less likely to have high severity crashes when all other factor were held constant. The lower AADTs as well as the lower speeds on such roadways would reduce severe accidents (27). In addition, since surface rehabilitation usually results in a lane closure, traffic would be forced to use a single lane alternating flow between traffic directions. Lane width was found to follow a pattern of larger widths resulted in less severe crashes when all other factors were held constant. Explanations for this could be attributed to the increased maneuverability for vehicles to avoid crashes.

Cost Calculation

To illustrate how the model results influence crash severity, assume the following scenario. A work zone crash occurs on a 55 mph, limited access, asphalt concrete 2-lane highway. The crash occurred during a rainy summer evening in rural Ohio resulting in an angle crash. Using this information, an equation predicting the probable severity can be found:

$$y = -0.048(If\ Summer) + 0.194(If\ No\ Access) - 0.333(If\ Raining) - 0.313(If\ Rural\ 2\ Lane) + 0.417(If\ Dusk) - 0.188(If\ Asphalt\ Concrete) + 0.285(If\ Midwest\ Region) + 0.216(If\ Angle\ Crash) + 0.24(If\ Rural) - 0.114(If\ Wet) + 0.051(Speed\ Limit)$$

It can be assumed that since it is a rural setting, the “rural 2 lane” and “rural” factors can be included in this equation. In addition, since it is raining, it is safe to assume the road surface would also be wet. Calculated, the probable severity, y, would equal 3.164 or a “Class C” injury according to the scale.

5. Local Business Impact Costs

5.1 Background

Local Business Impact Costs (LBICs) are the third of the three categories of impacts associated with roadway pavement rehabilitation work and quantified in this report. LBICs are defined as the economic impacts on local businesses from nearby pavement rehabilitation work zones caused by changes in customer spending and visitation behaviors. Despite being a well-documented challenge, there is little guidance on how engineers should quantify these impacts. Therefore, a national survey was conducted to determine customer preferences to different work zone durations as it related to their activity choices. Results were modeled from an ordered probit model with direct monetary relations taken from the survey response distributions.

5.2 Data Collection

The national LBIC survey was conducted through the Survey Monkey platform to limit costs and maximize the sample size. Originally, 425 responses were recorded then another 345 responses were solicited during the ensuing phases. Respondents were chosen to reflect US Census demographics and socioeconomic factors to allow a representative sample of the entire nation. Questions covered consumer spending habits among different activities (leisure, grocery shopping, home/houseware shopping), average travel times to said activities, and behavioral changes to travel if a work zone of variable durations is introduced to the trip. Respondents were asked how an increased travel time of 5, 20, or 40 minutes over a project duration of a day, week, or month would affect their travel choices. Respondents were provided five choices:

- "Still take the trip."
- "Reschedule the trip for another day/time while construction is still happening and the delay is still the same."
- "Reschedule the trip for another day/time after construction is completed and there is no longer a delay."
- "Go somewhere else."
- "Cancel trip entirely (including shopping online instead)."

This was asked for each of the three activity categories with construction duration doled out at a 33 percent probability. Overall, 770 survey responses were recorded before cleaning.

Since the survey was conducted electronically, all results were already formatted into an easy-to-use SPSS file so little cleaning/formatting was required. Even with mandatory responses and incentives to complete the survey, 55 respondents (7 percent) did not complete the survey in some form or another and had their responses removed from the final dataset. Final model results were calculated using the final 763 sample size.

Each respondent was asked several demographic questions to not only identify lacking response groups, but to also put results into context. Figure 2 shows the ages of respondents broken into several categories.

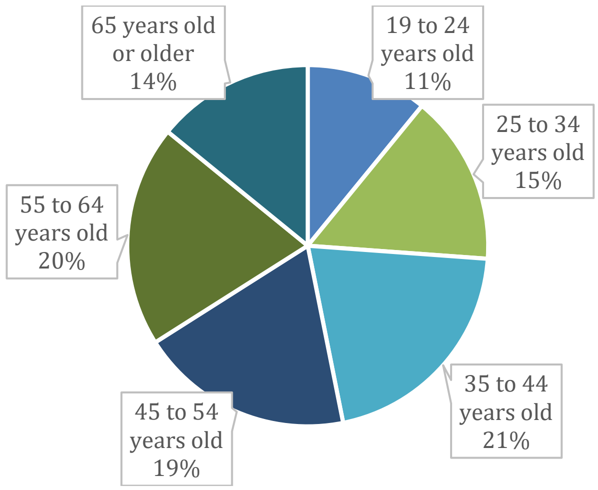


Figure 2: Age Distribution of Sample

Due to Institutional Research Board (IRB) regulations, all respondents had to be 19 years of age or older to take the survey. The age categories were matched to crash results in the previous section. Results were consistent compared to US Census 2015 estimates (29), with the percentage of individuals aged 19 to 24 years old matching census estimates, the percentage of individuals aged 25 to 34 years old about 3% more than census estimates, the percentage of individuals aged 35 to 44 years old about 5% less than census estimates, the percentage of individuals aged 45 to 54 years old about 1% less than census estimates, the percentage of individuals aged 55 to 64 years old about 3% less than census estimates, the percentage of individuals aged 65 years or older about 5% more than census estimates

Respondent gender (Figure 3), although not accounted for in the crash results, reflected national trends within ±5 percent.

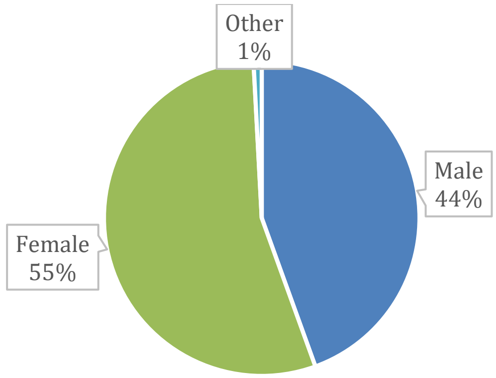


Figure 3: Gender Distribution of Sample

According to 2015 American Community Survey estimates, the US population is almost evenly split at 49 percent male and 51 percent female (28).

Regionally, shown in Figure 4, survey results showed an almost perfect match to census estimates for 2016 with variations under ±1 percent (28). Refer to the Appendix A for a table of states in each region.

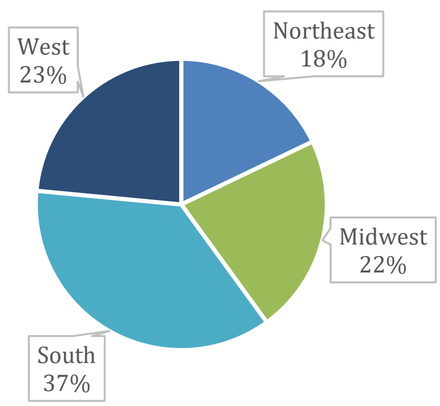


Figure 4: Regional Distribution of Sample

Household income, Figure 6, varied from census estimated data. While for household type, Figure 5, no records comparing to the national trends could be found.

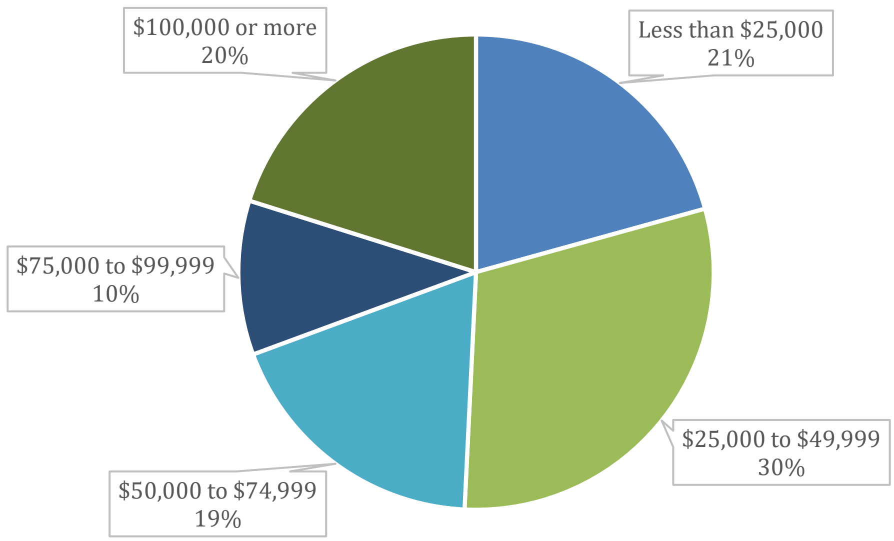


Figure 5: Income Distribution of Sample

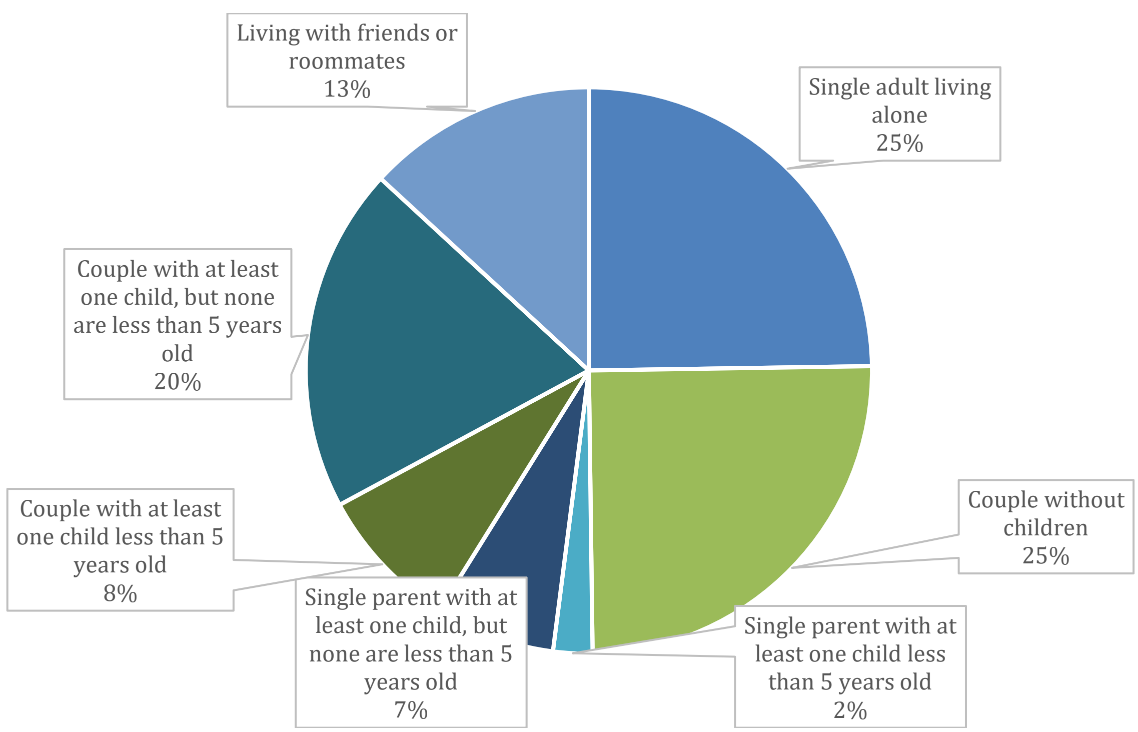


Figure 6: Household Type Distribution of Sample

Household income varied from the national estimates the most with the “$25,000 to $49,999” category at 6.5 percent over the national percentage (28). All other categories were less than ±5% of the national percentages.

Overall, a typical survey respondent was a 35- to 44-year-old female living either alone or with children in the Southern US region. Her household had a total income in the $25,000 to $49,999 range. Conversely, a person identifying as “other” in the 19 to 24-year-old range making between $75,000 and $99,999 a year in the Northeast region, while living alone with a child under 5 years of age, was the least likely to complete the survey. In the analysis, these infrequent choices would be use as the base case in the model.

5.3 Local Business Impact Costs Model Estimation

The most likely trip change choice for each driver through a given work zone is also calculated using an ordered probit regression model. This section introduces the model structure and estimation results.

Ordered Probit Regression Model

Again, the ordered probit regression model is the most appropriate method for predicting choice because this dependent variable is a) categorical, meaning that choices about whether to take the trip or not are mutually exclusive, and b) presented in an ordered scale, meaning that the choices move from ‘no deviation from regular behavior’ to a ‘complete change in behavior’.

The ordered probit regression model is similar to a continuous linear regression model, in that it first calculates a continuous underlying unitless “trip disruption/aggravation” score for driver that travels through a work zone based on the input independent variables. This score has no upper or lower limits, but a higher score translates to a more likely deviation from the original travel. This “trip disruption/aggravation” score equation can be written as:

$$y^* = \beta' x + \epsilon$$

Where:

y^* = Injury severity level

β = Matrix of estimated coefficients

x = Matrix of independent variables

ε = Error term (assumed to be normally distributed)

Independent variables describe driver characteristics, region characteristics, roadway characteristics, and project characteristics. These are all categorical, indicator variables (for ease in application). The coefficients provide relative weights for each independent variable, assuming all other variables are held constant.

Next, the driver trip choice categories are mapped to this underlying "trip disruption/aggravation" scale as demonstrated in Figure 7. One can see that the continuous "trip disruption/aggravation" score is partitioned into the scaled trip decisions, such that if a driver receives a score between γ_3 and γ_4., the most likely outcome would be for the driver to "go somewhere else". The thresholds between trip decisions are estimated specific for the model and do not need to be evenly spaced, highlighting the varying ranges of annoyance/impact that work zones that can occur within each avoidance behavior type.

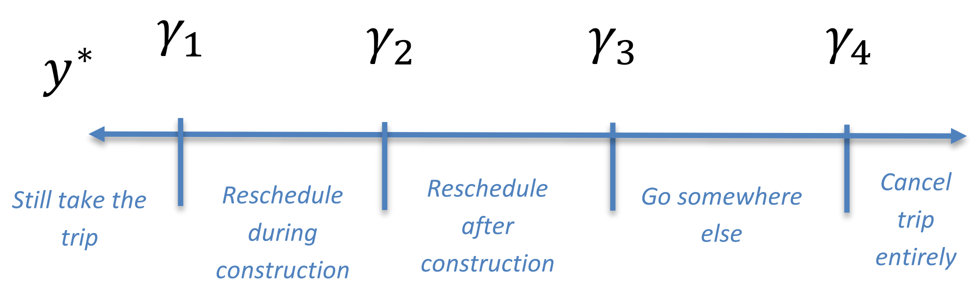


Figure 7: Trip Distribution/ Aggravation Scale

This mapping can also be written as:

$$y = \begin{cases} \text{Cancel trip entirely} & \text{if } y^* > \gamma_4 \\ \text{Go somewhere else} & \text{if } \gamma_3 \leq y^* < \gamma_4 \\ \text{Reschedule for after construction} & \text{if } \gamma_2 \leq y^* < \gamma_3 \\ \text{Reschedule during construction} & \text{if } \gamma_1 \leq y^* < \gamma_2 \\ \text{Still take the trip} & \text{if } y^* \leq \gamma_1 \end{cases}$$

The ordered probit model assumes independence of irrelevant alternatives, low collinearity, and a normal distribution of error terms. The model coefficients and thresholds were estimated using maximum likelihood estimation. The model was iteratively estimated, removing variables that were insignificant at the 99% confidence level until a final model was derived.

Estimation Results

The final model estimation results are presented in Table 14.

Table 14: Estimation Results

		Impacts on Business Type…					
		Grocery Shopping		Personal Shopping (e.g. Clothes or Home Goods)		Leisure Activity (e.g. Eat at a Restaurant or Go to a Movie)	
		Coeff.	*p-value*	*Coeff.*	*p-value*	*Coeff.*	*p-value*
Model Characteristics	**Choice Thresholds**						
	Still Take the Trip	< 0.914		< 0.363		< 1.298	
	Reschedule during construction	0.914	0.073	0.363	0.189	1.298	< 0.001
	Reschedule after construction	1.219	0.017	0.685	0.013	1.492	< 0.001
	Go somewhere else	2.024	< 0.001	1.832	< 0.001	2.255	< 0.001
	Cancel trip entirely	6.292	< 0.001	4.100	< 0.001	5.076	< 0.001
Region Characteristics	**US Region (Base: Northeast)**						
	West	0.271	0.012	-	-	-	-
	Community Type (Base: Rural)						
	Urban	0.331	0.015	-	-	-0.230	0.062
	Suburban	0.289	0.014	-	-	-0.262	0.016
Driver Characteristics	**Age (Base: 19 to 24 years old)**						
	25 to 34 years old	0.742	< 0.001	-	-	-	-
	35 to 44 years old	0.836	< 0.001	-	-	-	-
	45 to 54 years old	0.745	< 0.001	-	-	0.559	< 0.001
	55 to 64 years old	0.391	0.024	-	-	0.564	< 0.001
	65 years old or older	0.599	0.002	-	-	0.550	< 0.001
	Gender (Base: Female)						
	Male	-	-	-	-	-	-
	Other	-1.076	0.028	0.828	0.063	-	-
	Household Type (Base: Single Adult)						
	Single Parent with at least one child less than 5 years old	0.582	0.063	-	-	-	-
	Single Parent with at least one child, none less than 5 years old	-	-	-	-	-	-
	Couple without children	0.227	0.045	-	-	0.203	0.054
	Couple with at least one child less than 5 years old	-	-	0.263	0.082	0.565	0.001
	Couple with at least one child, none less than 5 years old	-	-	0.332	0.003	-	-
	Living with Friends or Roommates	0.268	0.066	-	-	-	-

	# Household Vehicles (Base: 0 vehicles)						
	1 Vehicle	0.616	0.001	0.309	0.001	0.792	< 0.001
	2 Vehicles	0.672	< 0.001	-	-	0.654	< 0.001
	3 to 5 Vehicles	1.054	< 0.001	0.229	0.042	0.776	< 0.001
	6 or More Vehicles	1.924	0.034	-2.114	0.014	-2.669	0.021
	Household Income (Base: Less than $25,000)						
	$25,000 to $49,999	-	-	0.366	0.002	-	-
	$50,000 to $74,999	0.206	0.077	0.500	< 0.001	-	-
	$75,000 to $99,999	-	-	0.651	< 0.001	-	-
	$100,000 or more	-	-	0.610	< 0.001	-	-
	Typical Daily Commute (Base: 5 Minutes or Less)						
	6 to 10 minutes	-	-	-	-	-	-
	11 to 20 minutes	-	-	-	-	-0.287	0.005
	21 to 40 minutes	-	-	-	-	-	-
	41 to 60 minutes	-	-	-	-	-0.562	< 0.001
	Longer than an hour	-	-	-	-	-0.366	0.091
Business Activity Characteristics	**Typical Time to Reach Business (Base: 5 Minutes or Less)**						
	6 to 10 minutes	0.471	< 0.001	0.736	< 0.001	-	-
	11 to 20 minutes	0.478	< 0.001	1.119	< 0.001	-	-
	21 to 40 minutes	0.451	0.015	1.136	< 0.001	0.207	0.043
	41 to 60 minutes	-	-	1.562	< 0.001	0.529	0.006
	Longer than an hour	-1.883	0.002	0.704	0.048	-	-
	Typical Amount Spent at Business (Base: Nothing)						
	$1 to $20	-1.840	< 0.001	-0.732	0.009	-	-
	$21 to $50	-1.599	< 0.001	-0.993	< 0.001	-	-
	$51 to $100	-1.747	< 0.001	-1.255	< 0.001	-	-
	$101 to $200	-1.868	< 0.001	-1.218	< 0.001	-	-
	More than $200	-1.697	< 0.001	-1.399	< 0.001	-1.183	0.001
Construction Characteristics	**Construction Delay (Base: Minor [+5 minutes])**						
	Average [+20 minutes]	1.924	< 0.001	1.512	< 0.001	1.791	< 0.001
	Significant [+40 minutes]	2.660	< 0.001	2.140	< 0.001	2.550	< 0.001
	Construction Duration (Base: Day)						
	Week	0.366	0.001	-	-	-	-
	Month	0.476	< 0.001	0.238	0.006	0.217	0.014

	-2 Log Likelihood	*4407.79*	< 0.001	*4524.86*	< 0.001	*4001.47*	< 0.001
	Pearson Chi-Squared	*8825.68*	< 0.001	*5537.91*	< 0.001	*5389.36*	< 0.001

Regional characteristic results showed that individuals across the country act relatively similar in their travel-deviation behavior. Only residents of the West census region were more likely to deviate from their grocery shopping travel than those from other census regions. Classifications of land (e.g. urban, rural or suburban) were statistically significant on grocery and leisure trips. Urban and suburban respondents were more likely to change their grocery trip plans when faced with construction compared to rural respondents. Leisure trips showed an opposite trend, where urban and suburban respondents were less likely to change trip plans compared to rural respondents. As grocery shopping can be deemed more mandatory than leisure trips, rural respondents, more likely limited in grocery store options, would be less inclined to reschedule or cancel a trip. However, as leisure trips could be seen as a luxury or abundant in options, rural respondents may be more willing to change trip plans.

Respondent demographics presented the most opportunities to influence trip-making decisions. Age categories showed the general trend that as individuals age, they become less likely to change grocery and leisure trip plans compared to all other age groups. This could be the result of older individuals being less willing to change routines than younger individuals as illustrated in several studies (32, 33, 34, 35).

Individuals from different household types reacted differently to work zone delays: Single adults and single parents with children older than 5 years old are less affected by delays than individuals in other household types; Single parents with children less than 5 years old are highly sensitive to travel delays on *grocery* trip and are more likely to change their travel; Couples without children are sensitive to travel delays on *grocery* and *leisure* trips and more likely to change these trips; Couples with children less than 5 years old are sensitive to travel delays on *personal shopping* trips and even more sensitive to *leisure* trips; Couples with children older than 5 are sensitive to travel delays on personal shopping trips, choosing to deviate from their travel plans; and Individuals living with roommates are most bothered by delays on grocery trips. Overall, households defined as having at least one child less than 5 years old, regardless of marriage status, were the most likely to change trip plans compared to all other household types.

The number of household vehicles had the most variety to statistically influence all trip types over almost every single category. Respondents were more likely to change grocery trip plans as the number of vehicles available increased. However, leisure and personal shopping trips showed an odd inverse effect. As the number of household vehicles increased, the likelihood to change personal shopping trips decreased before greatly declining at the “6 or more” category. Leisure trips showed a steadier response, but once a respondent reached the “6 or more” category, the same inversion occurred; albeit at a greatly increased affect. Reasons for this could not be immediately ascertained. Oddly enough, as the number of household vehicles could be an indicator of household wealth, household income did not reflect similar results. As household income increased, generally, the more likely a respondent was to change personal shopping trip plans. This could be an indicator of being able to afford more options therefore changing personal shopping locations would not be as detrimental.

Results to business activity showed that as travel time increased for grocery trips, respondents were less likely to change trip plans when all other factors were held constant. As grocery trips can be defined as the most mandatory of the three trip types defined in the survey, this result is logical. Personal shopping and leisure trips showed opposite trends with respondents being more likely to change plans the longer the travel time. The only exception to this was personal shopping trips that took longer than hour to make. This could be the result of rural isolation where options are severely limited; the same with grocery trips. Surprisingly, the amount of money typically spent at all trip types had a little affect in changing a respondent’s mind in changing their trip plans, when all other variable were held constant. While grocery trips were uniform in coefficient weight, personal shopping showed a more negative trend as the amount spent increased.

Finally, construction characteristics showed that delay time was significantly more influential than the duration of the project. For all trip types, as delay time increased, respondents were inclined to change their trip plans when all other factors were held constant. This factor was so influential that average delay (+20 minutes) resulted in a base threshold of “rescheduling after construction” while significant delay (+40 minutes) placed a base threshold of “go somewhere else” when all other factors were held constant. This finding illustrates the value of limiting work zone delay, communicating to the public construction activity, and scheduling construction at non-peak times to reduce traffic affected.

6. Pavement Rehabilitation Project Cost (PRPC) Tool

The three models are combined into a transferrable and easy-to-use Excel tool, seen in Figure 8. This section outlines the tool interface, how users may implement the tool, a description of the tool's methodology, and suggestions on how to utilize during construction project planning.

6.1 Tool Overview

The tool is designed to provide U.S. contractors and agencies with the ability to calculate costs associated with a roadway rehabilitation project, regardless of their past modeling experience. As such, the tool only requires users to collect and enter information about the roadway, surrounding area, and work zone. The spreadsheet then calculates the impact costs once the user clicks the "calculate" button. The calculations run in the background are outlined in the next section.

It is important to recognize that the tool generates a simulated population of drivers through a work zone that reflect the distribution of regional (or local) population demographics. Each time the tool is used, it generates a new simulated set of drivers that may provide slightly different LBIC results. To minimize variation in results and reduce the need to run the tool multiple times, the tool internally completes 10 iterations and presents the averages of these results. This number of iterations was identified as a natural limit for converging results.

The tool has population distributions built-in to represent the four regions of the United States (Northeast, South, Midwest, and West) that are generated from the 2010 US Census, shown below in Figure 8. A detailed list of states in each region is provided in the Appendix A.

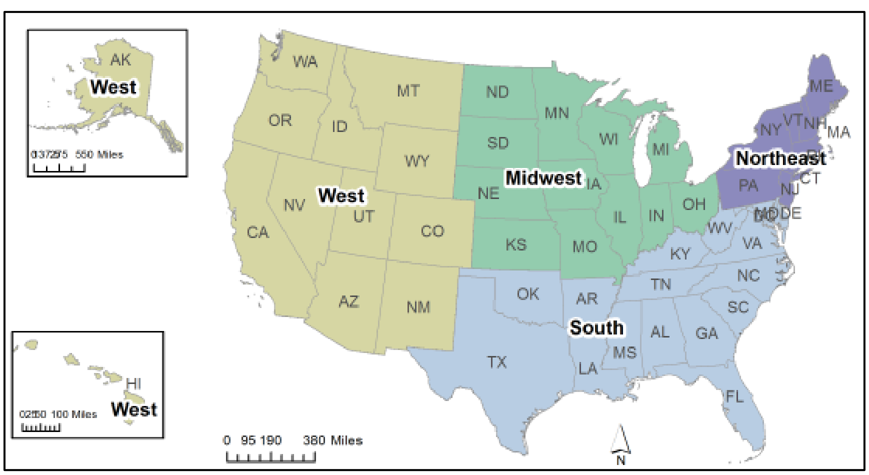


Figure 8: US Census Bureau Definitions of Demographic Regions

If users do not have localized population data, they may rely on this base data. However, if users have local demographic information, they may enter it into the tool to generate results that more accurately reflect the drivers seen in their area.

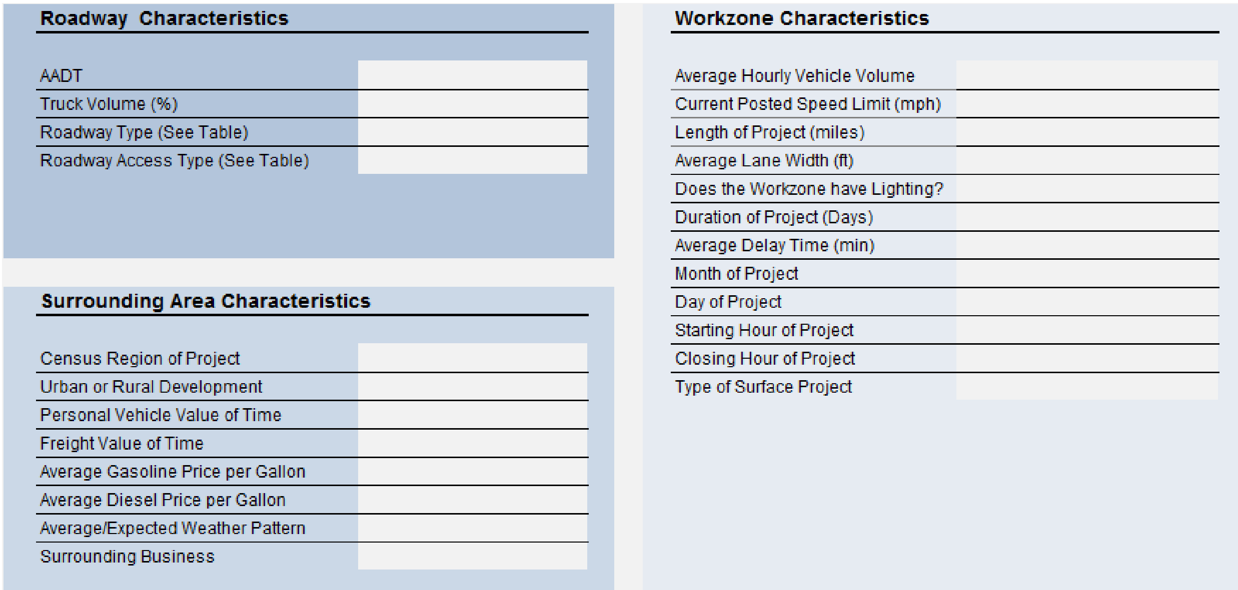
The Excel Workbook consists of five tabs: “Work Zone Characteristics”, “Vehicle Simulation”, “Regional Demographics”, “Crash Costs”, and “Reference Tables”. Only the “Work Zone Characteristics” tab requires data input to use the tool effectively; the other tabs illustrate the methodology and statistics used to compute the end results. This section provides an overview and brief explanation of each tab.

Work Zone Characteristics

This is the main tab of the tool where all inputs and outputs are shown. All inputs can be entered via user input or selected via drop-down box. Figure 8 below, shows the layout.

Figure 8: Cost Tool Overview

The user will spend most, if not all their time on this tab, so understanding it is key. The inputs required are divided into the three sections as illustrated in Figure 9.



Roadway Characteristics

AADT	
Truck Volume (%)	
Roadway Type (See Table)	
Roadway Access Type (See Table)	

Surrounding Area Characteristics

Census Region of Project	
Urban or Rural Development	
Personal Vehicle Value of Time	
Freight Value of Time	
Average Gasoline Price per Gallon	
Average Diesel Price per Gallon	
Average/Expected Weather Pattern	
Surrounding Business	

Workzone Characteristics

Average Hourly Vehicle Volume	
Current Posted Speed Limit (mph)	
Length of Project (miles)	
Average Lane Width (ft)	
Does the Workzone have Lighting?	
Duration of Project (Days)	
Average Delay Time (min)	
Month of Project	
Day of Project	
Starting Hour of Project	
Closing Hour of Project	
Type of Surface Project	

Figure 9: Variable Inputs

Users have 24 characteristics to describe a particular work zone across three different categories: Roadway Characteristics, Surrounding Area Characteristics, and Workzone Characteristics. Most inputs are determined via drop-down menus, including posted speed limit, so users are limited to certain scenarios. The variables needed to run the model are as follows:

Roadway Characteristics

INPUT	INPUT TYPE	DESCRIPTION	WHERE TO FIND
AADT	User-Defined	Annual Average Daily Traffic	State DOT/ Local Road Owning Agency Database
TRUCK VOLUME	User-Defined	Percent of AADT that is freight vehicles	State DOT/ Local Road Owning Agency Database
ROADWAY TYPE	Drop-Down List	Roadway classification as defined by DOT	State DOT/ Local Road Owning Agency Database
ROADWAY ACCESS TYPE	Drop-Down List	How traffic access is managed onto the roadway	State DOT/ Local Road Owning Agency Database

Surrounding Area Characteristics

INPUT	INPUT TYPE	DESCRIPTION	WHERE TO FIND
CENSUS REGION	Drop-Down List	Target state's US Census Region designation	US Census map provided
URBAN OR RURAL DEVELOPMENT	Drop-Down List	If project is located in a rural or urban area	Site visits, US Census designations
PERSONAL VEHICLE VALUE OF TIME	Drop-Down List	The value of time of the average personal vehicle	Provided
FREIGHT VALUE OF TIME	Drop-Down List	The value of time of the average freight vehicle	Provided
AVERAGE GASOLINE PRICE PER GALLON	User-Defined	Area average gasoline price per gallon	Site visits, AAA website
AVERAGE DIESEL PRICE PER GALLON	User-Defined	Area average diesel price per gallon	Site visits, AAA website
EXPECTED WEATHER PATTERN	Drop-Down List	Average weather conditions expected	Site visits, weather forecasts
SURROUNDING BUSINESS TYPE	Drop-Down List	Defines area business as leisure, personal, or grocery	Google Maps, surveys, site visits

Work Zone Characteristics

INPUT	INPUT TYPE	DESCRIPTION	WHERE TO FIND
AVERAGE HOURLY VEHICLE VOLUME	User-Defined	Average number of vehicles while work zone is present	Onsite counts, AADT conversion using percentages from Table 3
PRE-CONSTRUCTION SPEED LIMIT	Drop-Down List	Normally posted speed limit	Site visits
WORK ZONE SPEED LIMIT	Drop-Down List	Posted speed limit during construction	Site visits, traffic plans
LENGTH OF PROJECT	User-Defined	Total length of the work zone in miles	Work zone plans
AVERAGE LANE WIDTH	Drop-Down List	Lane width of the travel-way	Site visits, Google Earth
WORK ZONE LIGHTING?	Drop-Down List	Is an artificial light source present for roadway illumination?	Site visits, work zone plans
DURATION OF PROJECT	User-Defined	How many full days the project is expected to last	Work zone plans
AVERAGE DELAY TIME	User-Defined	The average delay time expected in minutes	Site visits, estimates, traffic plans
MONTH OF PROJECT	Drop-Down List	The starting month of the project resulting in delays	Work zone plans
DAY OF PROJECT	Drop-Down List	The starting day of the project resulting in delays	Work zone plans
STARTING HOUR OF THE PROJECT	Drop-Down List	The starting hour of the project resulting in delays	Work zone plans
CLOSING HOUR OF THE PROJECT	Drop-Down List	The closing hour of the project ending delays	Work zone plans
TYPE OF SURFACE	Drop-Down List	The majority surface type used in the project	Work zone plans

In addition, a benefit of the tool is the limited inputs required to create a report. At a minimum, the average hourly vehicle volume and average delay time are required to produce a predicted Road User Cost. Obviously, the more information provided, the more accurate the results. Several assumptions are made for the tool to function properly:

TOPIC	ASSUMPTION
GENERAL	If the starting and ending time if the project is not specified, it is assumed the project duration is 24 hours.
	The value of time for personal vehicle and freight is assumed to be uniform for all road users.
	The average hourly wage and compensation for personal users are assumed to be \$25.81 per hour and \$30.46 per hour, respectively.
BUSINESS IMPACT COSTS	All vehicles are attempting to utilize the specified business.
	Only one business type can be selected at a time.
	Time of day is not factored into the calculation.
CRASH MITIGATION COSTS	Driver’s age is 35 to 44 years old.
	If the specified weather pattern is “rain” or “snow”, the road condition will be assumed to be “wet” or “ice/snow”, respectively.
	The default crash type is assumed to be Property Damage Only (PDO).
	Only one of the most probable crash type determined will occur during the project duration.

As the user selects their inputs, the output section will automatically populate with the expected impact costs, shown in Figure 10.

User & Business Impact Cost Summary

Road User Costs		
Cost per Personal Vehicle	$	-
Cost per Freight Vehicle	$	-
Total Road User Cost...		
...per Hour	$	-
...per Work Day	$	-
...per Project Duration	$	-

Crash Mitigation Costs		
Most Likely Crash Type	PDO	
Total Crash Mitigation Cost...		
...per Hour	$	308.33
...per Work Day	$	7,400.00
...per Project Duration	$	7,400.00

Local Business Impact Costs		
Revenue Associated with Drivers Who Will...		
...Still Take Trip	$	-
...Reschedule w/ Construction	$	-
...Reschedule w/o Construction	$	-
...Go Somewhere Else	$	-
...Cancel Trip Entirely	$	-
Total Lost Revenue Cost...		
...per Hour	$	-
...per Work Day	$	-
...per Project Duration	$	-

TOTAL IMPACT COSTS...		
...per Hour	$	308.33
...per Day	$	7,400.00
...per Project Duration	$	7,400.00

Figure 10: Tool Outputs

The probable impact costs are displayed to the user by hour, day, total project duration among each of the sections. It should be noted the tool assumes at least one crash will occur regardless, so the default is assumed to be “Property Damage Only”. Additionally, the Local Business Impact Costs section will not begin to populate until the “Calculation” button is pressed by the user. This is because the tool must use an Excel macro code to compute this section through a Monte Carlo simulation, explained in detail in the next section.

Vehicle Simulation Tab

This tab displays the results of each simulated vehicle used to determine the probable business impact costs. Using user input and regional-specific census demographics, simulated vehicles are created via a Monte Carlo simulation of the Business Impacts Model. Figure 11 shows an example output of the simulation. Data supporting the model simulations can be seen in Appendix B.

SIMULATED VEHICLES									
Simulated Vehicle	Business Type	Age	Gender	Household Type	# Vehicles	Income	Daily Commute	Access Time	Amount Spent
1	Leisure	45 to 59	Male	Couple w/ Children under 18	2 personal vehs	$25,000 - $49,999	10 -19 min	41 to 60 min	$51 - $100
2	Leisure	25 to 34	Female	Single Alone	1 personal veh	$25,000 - $49,999	20 - 39 min	11 to 20 min	$1 - $20
3	Leisure	60 to 64	Male	Single Alone	0 personal vehs	>= $100,000	20 - 39 min	6 to 10 min	$1 - $20
4	Leisure	25 to 34	Male	Single Alone	2 personal vehs	$75,000 - $99,999	20 - 39 min	11 to 20 min	$21 - $50
5	Leisure	Under 25	Male	Couple No Children	1 personal veh	$75,000 - $99,999	20 - 39 min	11 to 20 min	$0
6	Leisure	45 to 59	Male	Couple w/ Children under 18	3 to 5 personal vehs	$75,000 - $99,999	>59 min	11 to 20 min	$21 - $50
7	Leisure	35 to 44	Female	Single Alone	1 personal veh	$50,000 - $74,999	10 -19 min	6 to 10 min	$101 - $200
8	Leisure	45 to 59	Male	Single Alone	2 personal vehs	<$25,000	5 - 9 min	11 to 20 min	$51 - $100
9	Leisure	35 to 44	Male	Single Parent w/ Children under 18	1 personal veh	$25,000 - $49,999	10 -19 min	11 to 20 min	$21 - $50
10	Leisure	45 to 59	Male	Couple No Children	1 personal veh	$50,000 - $74,999	5 - 9 min	Less than 5 min	$21 - $50
11	Leisure	Under 25	Female	Couple No Children	2 personal vehs	<$25,000	5 - 9 min	11 to 20 min	$51 - $100
12	Leisure	45 to 59	Male	Couple No Children	2 personal vehs	$75,000 - $99,999	20 - 39 min	21 to 40 min	$21 - $50
13	Leisure	25 to 34	Female	Couple w/ Children under 18	2 personal vehs	>= $100,000	5 - 9 min	Less than 5 min	$21 - $50
14	Leisure	35 to 44	Male	Single Parent w/ Children under 18	2 personal vehs	$25,000 - $49,999	20 - 39 min	6 to 10 min	$21 - $50
15	Leisure	45 to 59	Female	Couple No Children	3 to 5 personal vehs	$75,000 - $99,999	20 - 39 min	11 to 20 min	$1 - $20
16	Leisure	60 to 64	Male	Single Alone	1 personal veh	>= $100,000	20 - 39 min	11 to 20 min	$51 - $100
17	Leisure	Under 25	Female	Living w/ Roommates/Friends	2 personal vehs	$50,000 - $74,999	20 - 39 min	Less than 5 min	$51 - $100
18	Leisure	35 to 44	Female	Single Alone	3 to 5 personal vehs	$25,000 - $49,999	20 - 39 min	21 to 40 min	$1 - $20
19	Leisure	35 to 44	Male	Living w/ Roommates/Friends	3 to 5 personal vehs	$50,000 - $74,999	10 -19 min	21 to 40 min	$51 - $100
20	Leisure	65 or older	Female	Living w/ Roommates/Friends	1 personal veh	$25,000 - $49,999	10 -19 min	11 to 20 min	$1 - $20

Figure 11: Monte Carlo Simulation Results

To the right of this section, the associated coefficient of the simulated vehicle is displayed as well as the resultant probable choice and costs.

Regional Demographics Tab

This tab displays the census data characteristics used for the vehicle simulation section. Two tables are presented, a cumulative demographics table and the raw US Census Region Demographics table. There is no discrepancy between the values between the two tables.

Crash Costs Tab

This tab illustrates the crash characteristics pulled from the user inputs. Characteristics are identified by a binary system with a “1” signifying the used characteristic coefficient. Results of this tab are relayed back to the output section of the “Work zone Characteristics” tab.

Reference Tables Tab

All tables presented in the main report are displayed here for reference values. These tables are divided into four sections: Value of Time Tables, Operating Costs Tables, Time Modifier Tables, and Emission Cost Tables. Values from these tables are used by the tool to calculate the per hour, per day and project duration impact costs.

6.2 How to Use the Tool

To operate this tool, the user needs to follow these three steps:

1. Reset or Clear the Form by pressing the “Clear Form” button located on the far right of the “Work Zone Characteristics” tab.
2. Enter or select Roadway, Work Zone, and Surrounding Area Characteristics via the input boxes.
3. Calculate the Total Costs by pressing the “Calculate” button located on the far right of the “Work Zone Characteristics” tab.

It should be noted that the “Clear Form” button DOES NOT reset the vehicle simulation used in the Local Business Impact Costs section. The vehicle simulation automatically resets each time the “Calculate” button is pressed by the user.

To demonstrate, let the following conditions exist for a work zone as shown in Figure 12:

Roadway Characteristics

AADT	15000
Truck Volume (%)	5%
Roadway Type (See Table)	Two Lane Road (Arterial)
Roadway Access Type (See Table)	No Control

Surrounding Area Characteristics

Census Region of Project	Midwest
Urban or Rural Development	Urban
Personal Vehicle Value of Time	General Personal (Intercity)
Freight Value of Time	General Work/Business
Average Gasoline Price per Gallon	$ 3.20
Average Diesel Price per Gallon	$ 3.20
Average/Expected Weather Pattern	Clear
Surrounding Business	Leisure

Workzone Characteristics

Average Hourly Vehicle Volume	625
Current Posted Speed Limit (mph)	45
Length of Project (miles)	2
Average Lane Width (ft)	12 to 20 Feet
Does the Workzone have Lighting?	Yes
Duration of Project (Days)	8
Average Delay Time (min)	40
Month of Project	June
Day of Project	Tuesday
Starting Hour of Project	6:00 AM
Closing Hour of Project	5:00 PM
Type of Surface Project	Asphalt Concrete

Figure 12: Work Zone Example

Once the inputs are set as shown, the “Calculate” button is pressed to complete the results section. As the program is running, the user will see the impact costs begin to rise and summate with the other impact costs that were automatically calculated. Figure 13 below shows the final impact cost results.

User & Business Impact Cost Summary

Road User Costs		
Cost per Personal Vehicle	*$*	*21.87*
Cost per Freight Vehicle	*$*	*46.88*
Total Road User Cost...		
...per Hour	$	14,448.79
...per Work Day	$	158,936.71
...per Project Duration	$	1,271,493.72

Crash Mitigation Costs		
Most Likely Crash Type	PDO	
Total Crash Mitigation Cost...		
...per Hour	$	84.09
...per Work Day	$	925.00
...per Project Duration	$	7,400.00

Local Business Impact Costs		
Revenue Associated with Drivers Who Will...		
...Still Take Trip	*$*	*-*
...Reschedule w/ Construction	*$*	*-*
...Reschedule w/o Construction	*$*	*600.00*
...Go Somewhere Else	*$*	*37,980.00*
...Cancel Trip Entirely	*$*	*-*
Total Lost Revenue Cost...		
...per Hour	$	37,980.00
...per Work Day	$	417,780.00
...per Project Duration	$	3,342,240.00

TOTAL IMPACT COSTS...		
...per Hour	$	52,512.88
...per Day	$	577,641.71
...per Project Duration	$	4,621,133.72

Figure 13: Example Results

As you see, this particular work zone scenario had a total monetary impact of over $4.6 million during its eight day duration. It should be noted that the business impact costs is only for leisure activities. If we were to change the Surrounding Business Type to "Grocery" the following results may occur (Figure 14).

User & Business Impact Cost Summary

Road User Costs		
Cost per Personal Vehicle	*$*	*21.87*
Cost per Freight Vehicle	*$*	*46.88*
Total Road User Cost...		
...per Hour	$	14,448.79
...per Work Day	$	158,936.71
...per Project Duration	$	1,271,493.72

Crash Mitigation Costs		
Most Likely Crash Type	PDO	
Total Crash Mitigation Cost...		
...per Hour	$	84.09
...per Work Day	$	925.00
...per Project Duration	$	7,400.00

Local Business Impact Costs		
Revenue Associated with Drivers Who Will...		
...Still Take Trip	*$*	*200.00*
...Reschedule w/ Construction	*$*	*320.00*
...Reschedule w/o Construction	*$*	*450.00*
...Go Somewhere Else	*$*	*59,220.00*
...Cancel Trip Entirely	*$*	*-*
Total Lost Revenue Cost...		
...per Hour	$	59,220.00
...per Work Day	$	651,420.00
...per Project Duration	$	5,211,360.00

TOTAL IMPACT COSTS...		
...per Hour	$	73,752.88
...per Day	$	811,281.71
...per Project Duration	$	6,490,253.72

Figure 14: Alternative Example Results

Although some road users would still shop, the vast majority would likely go somewhere else in this scenario. Additionally, as people tend to spend more money on groceries compared to leisure trips, the overall impact costs has risen by nearly $1.9 million. Therefore, an alternative work zone design could be investigated to minimize these costs. Additionally, the tool calculates costs associated with a single business type at a time. If a parcel contains multiple business types, the tool can be run multiple times and the local business impact costs can be summed.

6.3 How to Apply the Tool

The tool can be applied in three significant ways:

Project Evaluation

First, the tool can characterize the road user, crash mitigation, and local business impacts of an existing project or projects that are being let for bid. For example, road owners can use the tool to conduct benefit-cost analyses based on their proposed plan, scheduling, material choices, work zone layout, etc. This information can put construction costs in perspective; for example, if a project is sped up, it reduces overall road user, crash, and local business impacts.

Project Planning

Second, the tool can be used in the project planning stage to evaluate possible innovative scheduling opportunities. The tool is able to quantify the cost generated per day or per hour, and, as such, can inform decision makers of the economic benefits of reducing construction times. Each complex scenario, whether it includes time of day, duration of the project, traffic volumes, seasons, etc., can be compared with a dollar-per project amount. Likely project impact costs can be calculated for many scenarios before work is begun to determine the most efficient and cost-effective approach. This should be done early in the planning process, perhaps as part of the LCCA and prior to any design work, in order to effectively influence the overall budget and schedule.

Community Outreach

Finally, the tool can be used to illustrate to local business owners the potential loss—or lack of loss—in revenue they could receive during construction. As found through previous studies (*17, 18, 19*), actual revenue losses are not nearly as extreme as owner-perceived revenue losses. Explaining that results assume worst-case scenario situations could help ease business owners' nerves and lower potential conflict points. Furthermore, increasing communication between the road owner and community regarding project updates and timelines has been shown to increase positive public perception and relations (*19*).

7. Conclusions

This study presents a comprehensive set of data-driven, nationally transferrable metrics that quantify the costs associated with asphalt and concrete pavement rehabilitation in terms of (a) road user costs, (b) crash mitigation costs, and (c) local business impact costs. These metrics are combined into a convenient Excel tool for users to input project variables and receive associated direct and indirect cost projections.

Specifically, costs are characterized in three ways: Road User Costs (RUCs) are defined as the total monetary and temporal costs experienced by both personal and freight vehicle road users when faced with delays caused by lane or total road closures due to rehabilitation work. Crash Mitigation Costs (CMCs) are defined as the cost associated with the most likely crash type to occur at a work zone. Local Business Impact Costs (LBICs) are defined as the economic impacts on local businesses from nearby pavement rehabilitation work zones caused by changes in customer spending and visitation behaviors.

Nationally representative data was collected for each Road User Cost category, including from the Highway Safety Information System (HSIS) and a unique national travel behavior survey conducted specifically for this study, and models to predict these costs for given roadway environments were estimated, using ordered probit regression models.

Overall, the results from the study indicate that impacts on road users, crashes and local businesses are governed not just by the project construction characteristics and the roadways on which the projects occur but the interactions with the drivers and vehicles on those roadways. As a result, when estimating these costs it is imperative to simulate the traffic that travels through the resulting work zones, and the tool developed in this project does this.

Additionally, the tool incorporates the difference in costs generated for personal and freight vehicles. Travel for leisure versus freight deliveries and vehicle class greatly affect the impact cost.

Finally, applications of the Excel workbook highlight that small increases in travel delay have significant impacts on local businesses.

8. References

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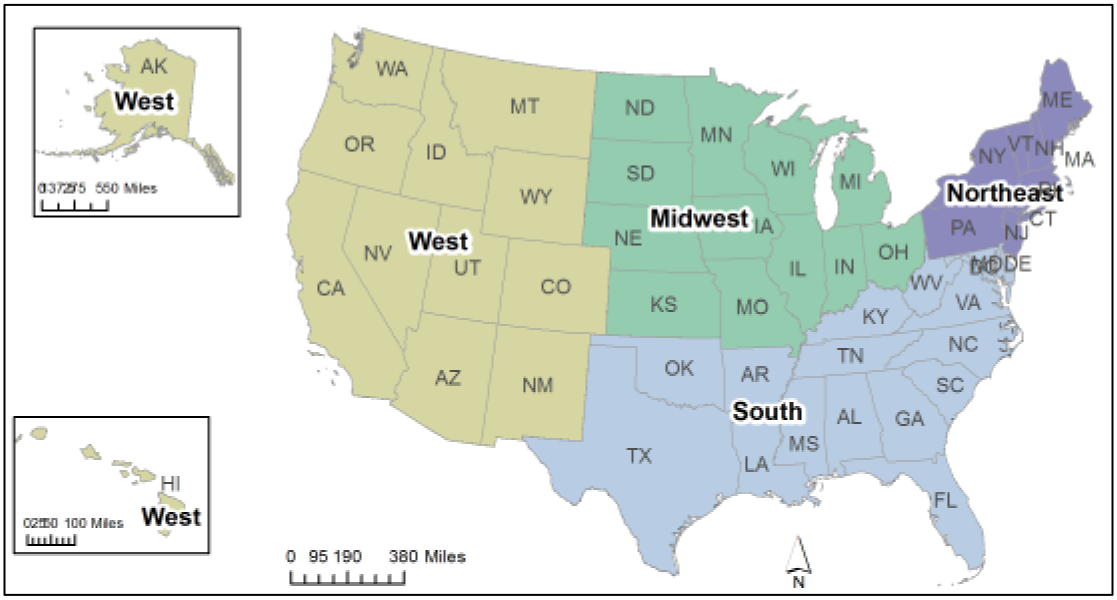
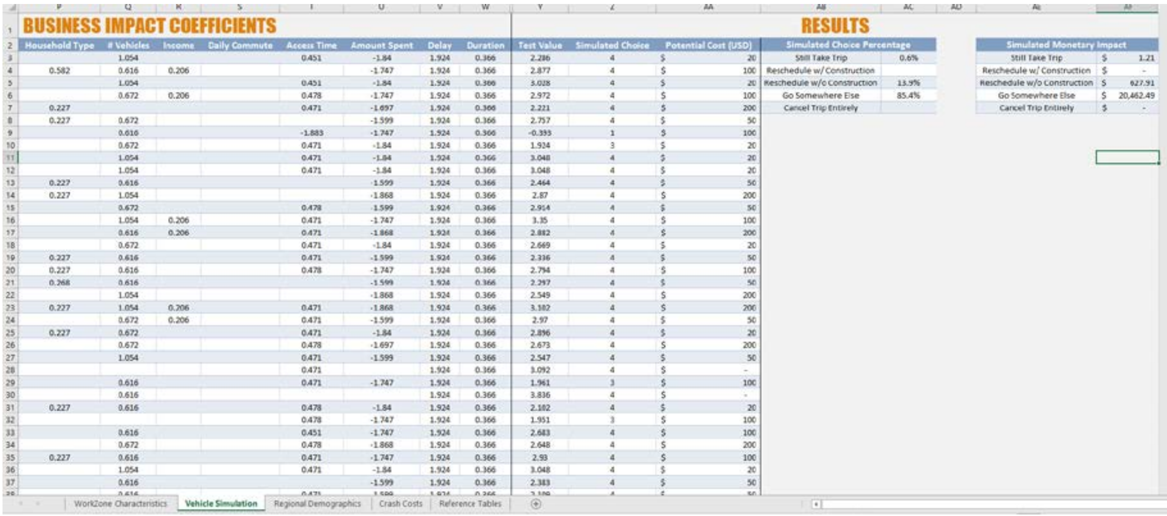
Appendix A: US Census Demographic Region Categories



Northeast	Midwest	South	West
Connecticut	Illinois	Alabama	Alaska
Maine	Indiana	Arkansas	Arizona
Massachusetts	Iowa	Delaware	California
New Hampshire	Kansas	District of Columbia	Colorado
New Jersey	Michigan	Florida	Hawaii
New York	Minnesota	Georgia	Idaho
Pennsylvania	Missouri	Kentucky	Montana
Rhode Island	Nebraska	Louisiana	Nevada
Vermont	North Dakota	Maryland	New Mexico
	Ohio	Mississippi	Oregon
	South Dakota	North Carolina	Utah

	Wisconsin	Oklahoma	Washington
		South Carolina	Wyoming
		Tennessee	
		Texas	
		Virginia	
		West Virginia	

Appendix B: Tool Tables



BUSINESS IMPACT COEFFICIENTS

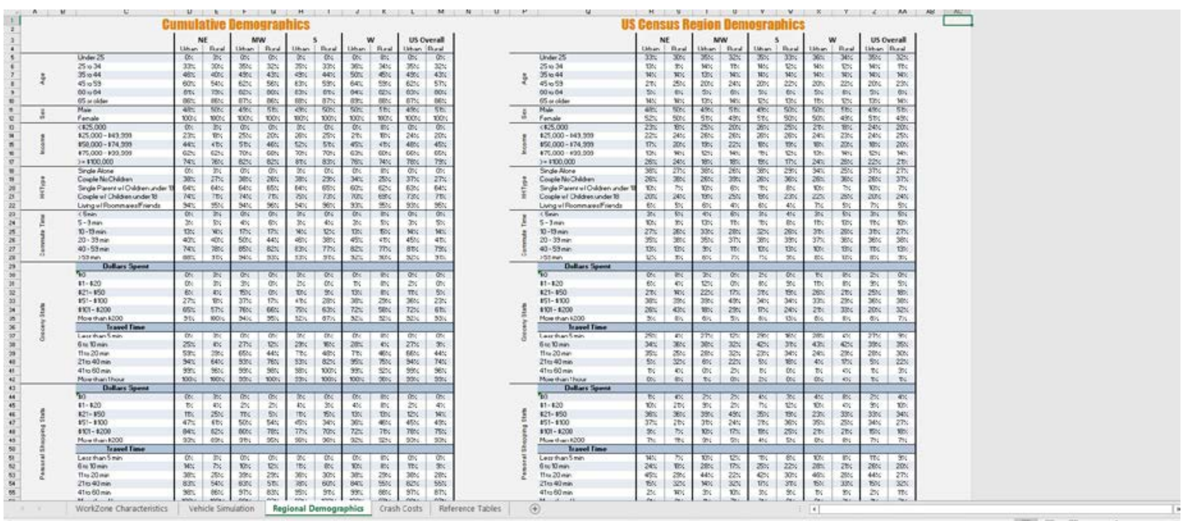
Household Type	# Vehicles	Income	Daily Commute	Access Time	Amount Spent	Delay	Duration	Test Value	Simulated Choice	Potential Cost (USD)
	1.054			0.451	-1.84	1.924	0.366	2.286	4	$ 20
0.582	0.616	0.206			-1.747	1.924	0.366	2.877	4	$ 100
	1.054			0.451	-1.84	1.924	0.366	3.028	4	$ 20
	0.672	0.206		0.478	-1.747	1.924	0.366	2.972	4	$ 100
0.227				0.471	-1.697	1.924	0.366	2.221	4	$ 200
0.227	0.672				-1.599	1.924	0.366	2.757	4	$ 50
	0.616			-1.883	-1.747	1.924	0.366	-0.393	1	$ 100
	0.672			0.471	-1.84	1.924	0.366	1.924	3	$ 20
	1.054			0.471	-1.84	1.924	0.366	3.048	4	$ 20
	1.054			0.471	-1.84	1.924	0.366	3.048	4	$ 20
0.227	0.616				-1.599	1.924	0.366	2.464	4	$ 50
0.227	1.054				-1.868	1.924	0.366	2.87	4	$ 200
	0.672			0.478	-1.599	1.924	0.366	2.914	4	$ 50
	1.054	0.206		0.471	-1.747	1.924	0.366	3.35	4	$ 100
	0.616	0.206		0.471	-1.868	1.924	0.366	2.882	4	$ 200
	0.672			0.471	-1.84	1.924	0.366	2.669	4	$ 20
0.227	0.616			0.471	-1.599	1.924	0.366	2.336	4	$ 50
0.227	0.616			0.478	-1.747	1.924	0.366	2.794	4	$ 100
0.268	0.616				-1.599	1.924	0.366	2.297	4	$ 50
	1.054				-1.868	1.924	0.366	2.549	4	$ 200
0.227	1.054	0.206		0.471	-1.868	1.924	0.366	3.182	4	$ 200
	0.672	0.206		0.471	-1.599	1.924	0.366	2.97	4	$ 50
0.227	0.672			0.471	-1.84	1.924	0.366	2.896	4	$ 20
	0.672			0.478	-1.697	1.924	0.366	2.673	4	$ 200
	1.054			0.471	-1.599	1.924	0.366	2.547	4	$ 50
				0.471		1.924	0.366	3.092	4	$ -
	0.616			0.471	-1.747	1.924	0.366	1.961	3	$ 100
	0.616					1.924	0.366	3.836	4	$ -
0.227	0.616			0.478	-1.84	1.924	0.366	2.182	4	$ 20
				0.478	-1.747	1.924	0.366	1.951	3	$ 100
	0.616			0.451	-1.747	1.924	0.366	2.683	4	$ 100
	0.672			0.478	-1.868	1.924	0.366	2.648	4	$ 200
0.227	0.616			0.471	-1.747	1.924	0.366	2.93	4	$ 100
	1.054			0.471	-1.84	1.924	0.366	3.048	4	$ 20
	0.616				-1.599	1.924	0.366	2.383	4	$ 50

RESULTS

Simulated Choice Percentage	
Still Take Trip	0.6%
Reschedule w/ Construction	
Reschedule w/o Construction	13.9%
Go Somewhere Else	85.4%
Cancel Trip Entirely	

Simulated Monetary Impact	
Still Take Trip	$ 1.21
Reschedule w/ Construction	$ -
Reschedule w/o Construction	$ 627.91
Go Somewhere Else	$ 20,462.49
Cancel Trip Entirely	$ -

WorkZone Characteristics | Vehicle Simulation | Regional Demographics | Crash Costs | Reference Tables



Cumulative Demographics

		NE Urban	NE Rural	MW Urban	MW Rural	S Urban	S Rural	W Urban	W Rural	US Overall Urban	US Overall Rural
Age	Under 25	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
	25 to 34	33%	30%	35%	32%	35%	33%	36%	34%	35%	32%
	35 to 44	48%	40%	49%	43%	49%	44%	50%	45%	49%	43%
	45 to 59	60%	54%	62%	56%	63%	59%	64%	59%	62%	57%
	60 to 64	67%	73%	62%	66%	63%	67%	64%	62%	63%	66%
	65 or older	86%	86%	87%	86%	88%	87%	89%	88%	87%	86%
Sex	Male	48%	50%	49%	51%	49%	50%	50%	51%	49%	51%
	Female	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Income	<$25,000	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
	$25,000 - $49,999	23%	18%	25%	20%	26%	25%	21%	18%	24%	20%
	$50,000 - $74,999	44%	41%	51%	46%	52%	51%	45%	41%	48%	45%
	$75,000 - $99,999	62%	62%	70%	66%	70%	70%	63%	60%	66%	65%
	>= $100,000	74%	76%	82%	82%	81%	83%	76%	74%	78%	79%
HHType	Single Alone	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
	Couple No Children	38%	27%	38%	26%	38%	29%	34%	25%	37%	27%
	Single Parent w/ Children under 18	64%	64%	64%	65%	64%	65%	60%	62%	63%	64%
	Couple w/ Children under 18	74%	71%	74%	71%	75%	73%	70%	69%	73%	71%
	Living w/ Roommates/Friends	94%	95%	94%	96%	94%	96%	93%	95%	93%	96%
Commute Time	< 5min	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
	5 - 9 min	3%	5%	4%	6%	3%	4%	3%	5%	3%	5%
	10 - 19 min	13%	16%	17%	17%	14%	12%	13%	15%	14%	14%
	20 - 39 min	40%	40%	50%	44%	46%	38%	45%	41%	45%	41%
	40 - 59 min	74%	78%	85%	82%	83%	77%	82%	77%	81%	79%
	>59 min	88%	91%	94%	93%	93%	91%	92%	90%	92%	91%
Grocery Stats	**Dollars Spent**										
	$0	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
	$1 - $20	0%	3%	3%	0%	2%	0%	1%	8%	2%	0%
	$21 - $50	6%	4%	15%	0%	10%	5%	13%	8%	11%	5%
	$51 - $100	27%	18%	37%	17%	41%	28%	38%	29%	36%	23%
	$101 - $200	65%	57%	76%	66%	75%	63%	72%	58%	72%	61%
	More than $200	91%	100%	94%	95%	92%	87%	92%	92%	92%	93%
	Travel Time										
	Less than 5 min	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
	6 to 10 min	25%	8%	27%	12%	29%	16%	28%	4%	27%	9%
	11 to 20 min	59%	39%	65%	44%	71%	48%	71%	46%	66%	44%
	21 to 40 min	94%	64%	93%	76%	93%	82%	95%	75%	94%	74%
	41 to 60 min	99%	96%	99%	98%	98%	100%	99%	92%	99%	96%
	More than 1 hour	100%	100%	99%	100%	99%	100%	100%	98%	99%	99%
Personal Shopping Stats	**Dollars Spent**										
	$0	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
	$1 - $20	1%	4%	2%	2%	4%	3%	4%	8%	2%	4%
	$21 - $50	11%	25%	11%	5%	11%	15%	13%	13%	12%	14%
	$51 - $100	47%	61%	50%	54%	45%	34%	36%	46%	45%	49%
	$101 - $200	84%	82%	80%	78%	77%	70%	72%	71%	78%	75%
	More than $200	93%	69%	91%	95%	98%	96%	92%	92%	93%	93%
	Travel Time										
	Less than 5 min	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
	6 to 10 min	14%	7%	10%	12%	11%	8%	10%	8%	11%	9%
	11 to 20 min	38%	25%	39%	29%	38%	30%	38%	29%	38%	28%
	21 to 40 min	83%	54%	83%	51%	38%	60%	84%	55%	82%	55%
	41 to 60 min	98%	86%	97%	83%	95%	91%	99%	88%	97%	87%

US Census Region Demographics

		NE Urban	NE Rural	MW Urban	MW Rural	S Urban	S Rural	W Urban	W Rural	US Overall Urban	US Overall Rural
Age	Under 25	33%	30%	35%	32%	35%	33%	36%	34%	35%	32%
	25 to 34	13%	9%	14%	11%	14%	12%	14%	12%	14%	11%
	35 to 44	14%	14%	13%	14%	14%	14%	14%	14%	14%	14%
	45 to 59	21%	25%	20%	24%	20%	22%	20%	22%	20%	23%
	60 to 64	5%	6%	5%	6%	5%	6%	5%	6%	5%	6%
	65 or older	14%	14%	13%	14%	12%	13%	11%	12%	13%	14%
Sex	Male	48%	50%	49%	51%	49%	50%	50%	51%	49%	51%
	Female	52%	50%	51%	49%	51%	50%	50%	49%	51%	49%
Income	<$25,000	23%	18%	25%	20%	26%	25%	21%	18%	24%	20%
	$25,000 - $49,999	22%	24%	26%	26%	26%	26%	24%	23%	24%	25%
	$50,000 - $74,999	17%	20%	19%	22%	18%	19%	18%	20%	18%	20%
	$75,000 - $99,999	13%	14%	12%	14%	11%	12%	13%	14%	12%	14%
	>= $100,000	26%	24%	18%	18%	19%	17%	24%	26%	22%	21%
HHType	Single Alone	38%	27%	38%	26%	38%	29%	34%	25%	37%	27%
	Couple No Children	26%	38%	26%	39%	26%	36%	26%	36%	26%	37%
	Single Parent w/ Children under 18	10%	7%	10%	6%	11%	8%	10%	7%	10%	7%
	Couple w/ Children under 18	20%	24%	19%	25%	19%	23%	22%	26%	20%	24%
	Living w/ Roommates/Friends	6%	5%	6%	4%	6%	4%	7%	5%	7%	5%
Commute Time	< 5min	3%	5%	4%	6%	3%	4%	3%	5%	3%	5%
	5 - 9 min	10%	9%	13%	11%	11%	8%	11%	10%	11%	10%
	10 - 19 min	27%	26%	33%	28%	32%	26%	31%	26%	31%	27%
	20 - 39 min	35%	38%	35%	37%	38%	39%	37%	36%	36%	38%
	40 - 59 min	13%	13%	9%	11%	10%	13%	10%	13%	11%	13%
	>59 min	12%	9%	6%	7%	7%	9%	8%	10%	8%	9%
Grocery Stats	**Dollars Spent**										
	$0	0%	8%	3%	0%	2%	0%	1%	8%	2%	0%
	$1 - $20	6%	4%	12%	0%	8%	5%	11%	8%	9%	5%
	$21 - $50	21%	14%	22%	17%	31%	19%	26%	21%	25%	18%
	$51 - $100	38%	39%	39%	49%	34%	34%	33%	29%	36%	38%
	$101 - $200	26%	43%	18%	29%	17%	24%	21%	33%	20%	32%
	More than $200	9%	8%	6%	5%	8%	13%	8%	8%	8%	7%
	Travel Time										
	Less than 5 min	25%	4%	27%	12%	29%	16%	28%	4%	27%	9%
	6 to 10 min	34%	36%	38%	32%	42%	31%	43%	42%	39%	35%
	11 to 20 min	35%	25%	28%	32%	23%	34%	24%	29%	28%	30%
	21 to 40 min	5%	32%	6%	22%	5%	18%	4%	17%	5%	22%
	41 to 60 min	1%	4%	0%	2%	1%	0%	1%	4%	1%	3%
	More than 1 hour	0%	8%	1%	0%	2%	0%	0%	4%	1%	1%
Personal Shopping Stats	**Dollars Spent**										
	$0	1%	4%	2%	2%	4%	3%	4%	8%	2%	4%
	$1 - $20	10%	21%	9%	2%	7%	12%	10%	4%	9%	10%
	$21 - $50	36%	36%	39%	49%	35%	19%	23%	33%	33%	34%
	$51 - $100	37%	21%	31%	24%	31%	36%	35%	25%	34%	27%
	$101 - $200	9%	7%	10%	17%	19%	25%	21%	21%	15%	18%
	More than $200	7%	11%	9%	5%	4%	5%	8%	8%	7%	7%
	Travel Time										
	Less than 5 min	14%	7%	10%	12%	11%	8%	10%	8%	11%	9%
	6 to 10 min	24%	18%	28%	17%	25%	22%	28%	21%	26%	20%
	11 to 20 min	45%	29%	44%	22%	42%	30%	46%	28%	44%	27%
	21 to 40 min	15%	32%	14%	32%	17%	31%	15%	33%	15%	32%
	41 to 60 min	2%	14%	3%	10%	3%	9%	1%	9%	2%	11%

WorkZone Characteristics | Vehicle Simulation | Regional Demographics | Crash Costs | Reference Tables

Automatically populates with information from the "Workzone Characterstics" tab.

Probable Crash Severity: PDO

Crash Characteristics

Weather	
Clear	0
Cloudy	0
Rain	0
Snow	0
Other	0

Census Region	
Midwest	1
Northeast	0
South	0
West	0

Season	
Spring	0
Summer	1
Fall	0
Winter	0

Accident Type	
Ran off Road	0
Struck Object	0
Rear End	1
Sideswipe	0
Angle	0
Other	0

Driver Age	
Under 25	0
25 to 34	0
35 to 44	1
45 to 54	0
55 to 64	0
Over 64	0

Surrounding Locale	
Rural	0
Urban	0

Day of Week	
Sunday	0
Monday	0
Tuesday	1
Wednesday	0
Thursday	0
Friday	0
Saturday	0

Road Characteristics

Lighting	
Daylight	0
Dusk	0
Dawn	0
Dark - Lighted Roadway	0
Dark - Roadway Not Lighted	0

Road Condition	
Dry	0
Wet	0
Ice/Snow	0

Raodway Access	
No Access Control	1
Partial Control	0
Full Control	0

Roadway Classification	
Urban Freeway	0
Urban Freeway Less than 4 Lanes	0
Urban 2 Lane Road	0
Urban Multilane Divided Non-Freeway	0
Urban Multilane Undivided Non-Freeway	0
Rural Freeway	0
Rural Freeways Less Than 4 Lanes	0
Rural 2 Lane Roads	0
Rural Multilane Divided Non-Freeway	0
Rural Multilane Undivided Non-Freeway	0
Other	0

Lane Width	
1 to 11 Feet	0
12 to 20 Feet	1
21 to 30 Feet	0
Greater than 30 Feet	0

Roadway Surface Type	
Asphalt Concrete	1
Portland Cement Concrete	0
Other	0

WorkZone Characteristics | Vehicle Simulation | Regional Demographics | **Crash Costs** | Reference Tables

Value Of Time Tables

Mode and Trip Purpose	Recommended Value of Time	
AUTO		
Personal (local)	50%	Wage
Personal (intercity)	70%	Wage
Business	100%	Compensation
Freight		
In-Vehicle Business	100%	Compensation
Excess (Waiting Time) Business	100%	Compensation

AASHTO/FHWA Recommended Values of Time

Industry	AvG Hourly Earnings ($/hr)	AvG Hourly Compensation ($/hr)
All Employees (Private)	$25.81	$30.46
Construction	$28.33	
Manufacturing	$26.16	
Transportation and Warehousing	$23.41	$28.10
Utilities	$38.35	$46.39
Information	$36.98	
Professional and Business Services	$30.97	
Education and Health Services	$25.87	
Leisure and Hospitality	$15.01	

Average Earnings/Compensation by Industry as of September 2016 BLS Estimates

Travel Purpose	Personal V
General Personal (local)	$12.91
General Personal (intercity)	$18.0
General Work/Business	$30.9
Transport & Warehousing	
Utilities	

Sample Values of Time for Different Secto

Census Region	Average Vehicle Occupancy	Margin of Error
U.S. Overall	1.07	0.01
Northeast	1.06	0.01
Midwest	1.06	0.01
South	1.14	0.02
West	1.08	0.01

American Community Survey 2006 - 2010 Five-Year Estimates for Average Vehicle Occupancy

Operating Cost Tables

Free Flow Speed	Small Car (gal/min)	Big Car (gal/min)	SUV (gal/min)	2-Axle SU (gal/min)	3-Axle SU (gal/min)	Combo (gal/min)
20	0.011	0.022	0.023	0.074	0.102	0.198
25	0.013	0.026	0.027	0.097	0.133	0.242
30	0.015	0.03	0.032	0.122	0.167	0.284
35	0.018	0.034	0.037	0.149	0.203	0.327
40	0.021	0.038	0.043	0.177	0.241	0.369

Traffic Speed	Personal Vehicle (C
25	1.2
35	1.65
45	2.22
55	2.91

WorkZone Characteristics | Vehicle Simulation | Regional Demographics | Crash Costs | **Reference Tables**